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[*Continued on page (III) of Cover.*

ELECTRICAL DEVELOPMENTS IN THE U.S.S.R.

By ALLAN MONKHOUSE, Member.

[*Paper received* 28*th November*, 1933, *in revised form* 7*th September*, 1934, *and in final form* 10*th May*, 1935; *read before* THE INSTITUTION 10*th January*, *before the* MERSEY AND NORTH WALES (LIVERPOOL) CENTRE 7*th January*, *before the* NORTH-WESTERN CENTRE 8*th January*, *before the* EAST MIDLAND SUB-CENTRE 15*th January*, *before the* NORTH MIDLAND CENTRE 22*nd January*, *before the* WESTERN CENTRE 18*th March*, *before the* SCOTTISH CENTRE *at Edinburgh*, 26*th March*, *before the* SCOTTISH CENTRE *at Aberdeen*, 28*th March*, *before the* IRISH CENTRE *at Belfast*, 4*th April*, *before the* IRISH CENTRE *at Dublin*, 5*th April*, *before the* SOUTH MIDLAND CENTRE 8*th April*, *and before the* TEES-SIDE SUB-CENTRE 15*th April*, 1935.]

SUMMARY.

The growth in the use of electrical energy in the Soviet Union in connection with the industrial development schemes of the Soviet Government is outlined, and details are included of developments in the use of peat fuel in large power stations. Some particulars are given of the thermal-electric power stations which are being built in many parts of the Union, and of the hydro-electric developments of the electrification authorities. Some outputs are shown for 10 stations where British plant is installed.

Particulars and illustrations are given showing the trend of the general lay-out of power stations, together with details of a typical station designed for an installed generating capacity of 250 000 kW. Four stations of this type are now under construction.

The standardization work of the Soviet authorities in relation to generating, transforming, and transmission equipment, is outlined.

The paper terminates with a brief reference to electrical manufacturing developments, railway electrification, and research.

INTRODUCTION.

The first State planning-organization set up by the Soviet Government when it entered upon its State-controlled scheme for Russia's economic development was the State Commission for the Electrification of Russia, appointed in 1921 and more generally known as "G.O.E.L.R.O." In instituting this Commission, Lenin emphasized the necessity of providing ample supplies of cheap electrical power as a basis for the future planned industrial development of the country.

From 1923 onwards the construction of some 56 large electric power stations in accordance with the general electrification plans of G.O.E.L.R.O., and the building of over 8 000 miles of 110-kV, 115-kV, 160-kV, and 220-kV overhead lines with their distribution substations, have provided one of the most spectacular developments in a country where rapidly-growing industrial activities as a whole have attracted the world's attention.

During this period the centralized control of the electric-supply and power-station-construction authorities has passed through many changes in its organization. At the present time the control of the majority of these activities is concentrated in a special section of the Commissariat of Heavy Industries known as "Glavenergo."

This body is now responsible for approximately 65 per cent of the power generating plant in the U.S.S.R., and for practically the whole of the power transmission and distribution systems. The actual generation figures for 1932 and 1933 are given in Table 1.

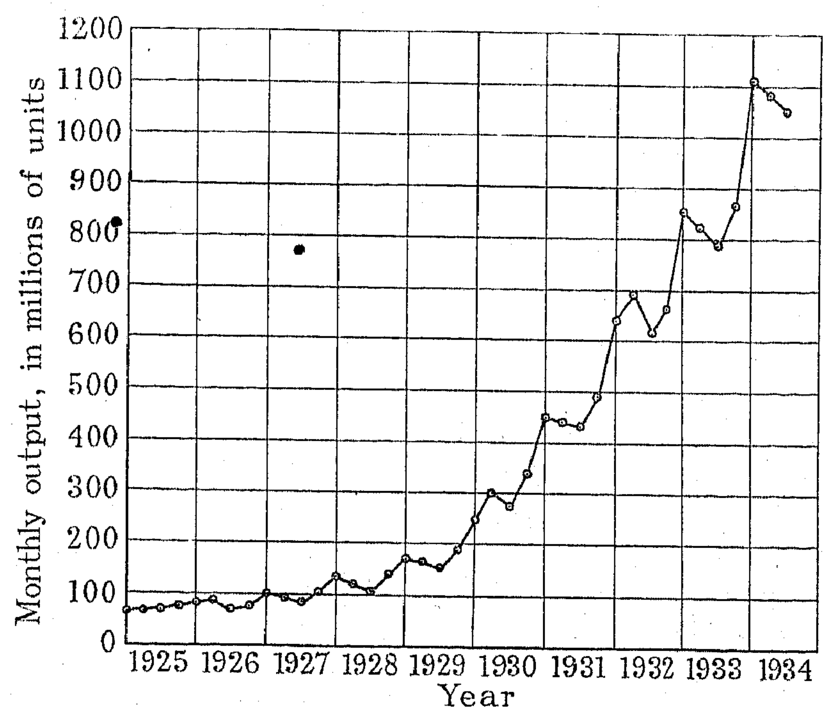

FIG. 1.—Monthly output of central and district power stations controlled by Glavenergo, 1925–1934.

TABLE 1.

	1932		1933	
	Millions of units	Per cent	Millions of units	Per cent
Glavenergo stations	8 297·3	61·9	10 252·0	64·5
Industrial stations .	4 121·9	30·9	4 566·8	29·0
Commercial stations	734·0	5·5	780·0	4·9
Agricultural stations	74·0	0·5	92·0	0·6
Transport stations ·	163·0	1·2	165·0	1·0
Total	13 390·2	100	15 855·8	100

TABLE 2.

List of Electricity Supply

Name of district authority	District	Number of stations			Total installed generating capacity (in thousands of kW)		Average installed generating capacity (in thousands of kW)	
		Straight condensing	Pass-out heating	Hydro-electric	Jan., 1933	Jan., 1934	1932	1933
Mos-Energo	Moscow	7	4	—	544·5	613·5	531·3	577·0
Len-Energo	Leningrad	5	2	2	323·4	491·4	322·2	358·0
Iv-Energo	Ivanovo-Vosnesensk	2	3	—	131·3	129·3	118·1	130·1
Ural-Energo*	Urals	5	—	—	157·1	219·0	141·7	173·0
Sevkav-Energo	North Caucasia	5	2	—	123·1	140·3	119·5	117·0
Grosni Oil-Fields	North Caucasia	1	1	—	32·4	32·4	30·7	32·4
Briansk	West Central Russia	1	3	—	47·8	22·0	46·0	22·0
Voronesh	West Central Russia	1	—	—	—	24	—	6
Krim-Energo	Crimea	4	—	—	10·5	11·1	8·0	9·6
Saratov Central	Lower Volga	1	—	—	22·5	22·5	22·5	22·5
Stalingrad Central	Lower Volga	—	1	—	51·0	51·0	51·0	51·0
Nijni Novgorod (Gorki)	Mid Volga	1	—	—	158·0	204·0	154·2	169·5
Samara	Mid Volga	1	—	—	15·2	15·2	15·2	15·2
Archangel	Northern Province	2	—	—	16·4	16·4	16·4	16·4
Kondopoj Hydro-Electric	Karellia	—	—	1	4·5	4·5	4·5	4·5
Novosibirsk†	Siberia	1	—	—	5·5	11·5	5·5	10·0
Donenergo	Eastern Ukraine	8	1	—	460·1	456·4	445·0	445·5
Har-Energo	Harkov	2	—	—	68·7	73·5	68·7	67·5
Zukr-Energo (Kiev)	Western Ukraine	5	—	—	39·9	39·9	39·9	39·9
Yush-Energo (Odessa)	Southern Ukraine	2	—	—	33·8	39·8	33·8	39·3
Dnieper-Energo	Central Ukraine	4	—	1	374·0‡	526·0	171·6	412·0
Zak-Energo	Transcaucasia	—	—	7	28·0	52·0	24·0	29·0
Baku Oil-Fields	Baku	2	1	—	154·9	158·5	140·9	158·5
Belgres	White Russia	1	—	—	20·0	20·0	20·0	20·0
Kazan	Kazan (Volga)	1	1	—	—	24·0	—	21·5
Central Asia-Energo	Kadirya	—	—	1	—	13·0	—	6·0
Totals	—	62	19	12	2 822·6	3 411·2	2 530·7	2 953·4

* The figures for the Ural district do not include the power plant at Beresniki Chemical Works, which has an installed capacity of 83 200 kW, and the power plant at Magnitogorsk Steelworks, which has an installed capacity of 48 000 kW.
† Does not include Kuznetsk Steelworks plant at Stalinsk, with an installed capacity of 72 000 kW.
‡ Includes Dnieprostroi Hydro-electric Station, where 310 000 kW of installed plant was put into service in the autumn of 1932.

The majority of the stations not under Glavenergo are those at large industrial plants, and these include:—

Magnitogorsk Steelworks	(48 000 kW)
Kuznetsk Steelworks	(72 000 kW)
Beresniki Chemical Works	(83 200 kW)
Baku Oil Fields	(154 900 kW)
Grosni Oil Fields	(32 400 kW)

The two last-mentioned authorities now work very closely with Glavenergo, and they have therefore been included in the list of Glavenergo undertakings shown in Table 2.

The rapid growth in the use of electrical power in the U.S.S.R., which has resulted from the fulfilment of the plans of the G.O.E.L.R.O., can readily be seen from Fig. 1. It will be noted that the monthly winter power output of the stations which now come under the control of Glavenergo has grown from approximately 75 million units to 1 100 million units in the last 10 years.

The chief features in the electrification of the European part of the U.S.S.R. are shown in Fig. 2. On this map the two figures against certain power stations show the present and the intended ultimate generating capacity of the stations.

In drawing up their plans the G.O.E.L.R.O. engineers found themselves confronted with certain facts which led them to embark upon important development work, much of which has in itself constituted a departure from established European practice. In the first place the industrial districts of North European Russia, i.e. Leningrad, Moscow, the cotton manufacturing district centred at Ivanovo Vosnesensk and the Gorki (Nijni Novgorod) district, where many large engineering works are being established, are far removed from the bituminous and anthracite coalfields of the Ukraine or the oilfields situated on the shores of the Caspian Sea. For economic and strategic reasons it was considered necessary to make these northern industrial areas independent of fuel supplies from the Ukraine and Caucasia, and

TABLE 2—*continued.*

Authorities Reporting to Glavenergo.

Average load (in thousands of kW)		Fuels employed (percentages)				Total electrical energy generated, in millions of kWh		Station requirements as a percentage of total generated energy		Total amount of heat distributed from station for heating purposes, in mega-calories	
1932	1933	Coal	Lignite	Peat	Oil and natural gas	1932	1933	1932	1933	1932	1933
276·0	334·8	11	31	40	18	2 416·6	2 937·2	7·4	7·4	621·9	732·7
173·5	197·0	21§	—	30	20	1 522·7	1 724·7	5·5	5·9	182·6	352·3
29·1	53·3	8	—	86	6	255·4	467·4	7·8	6·9	139·9	161·0
58·7	77·0	96	—	4	—	516·7	674·1	6·2	6·0	9·7	27·9
40·8	46·3	100	—	—	—	360·3	405·5	8·7	9·0	26·7	29·5
13·0	16·3	—	—	—	100	113·5	143·1	7·4	4·9	—	—
11·6	3·1	20	—	80	—	97·0	30·3	11·8	17·6	23·1	—
—	—	—	—	100	—	—	7·4	—	14·9	—	—
3·62	4·4	100	—	—	—	31·4	38·6	5·7	6·5	—	—
6·9	7·2	100 (anthracite waste)				60·3	65·4	10·5	10·0	—	—
14·2	19·1	100 (anthracite waste)				124·3	167·4	15·1	13·4	43·1	50·5
59·6	58·8	—	—	100	—	525·2	515·5	6·7	7·0	—	—
5·4	6·0	Oil and other fuel				47·3	52·4	8·5	8·1	7·5	2·7
6·7	8·2	Wood and coal				59·3	71·6	8·6	6·5	—	—
1·28	1·31	Hydro-electric				11·3	11·5	1·0	—	—	—
3·2	4·4	100	—	—	—	28·0	38·4	5·5	8·0	—	—
148·5	195·0	100 (anthracite waste)				1 303·1	1 706·9	10·1	8·7	742·0	843·2
25·1	26·4	100	—	—	—	220·4	230·7	8·3	9·7	—	19·5
14·7	16·8	100	—	—	—	129·9	148·5	9·2	9·3	—	—
16·4	16·9	100	—	—	—	144·1	147·9	5·3	5·3	1·8	—
28·2	62·6	Mainly hydro-electric				248·0	550·5	7·4	3·7	—	—
15·5	13·5	Hydro-electric				135·6	118·6	0·4	0·6	—	—
68·4	78·8	—	—	—	100	599·6	691·2	6·0	6·0	—	158·1
6·9	7·5	—	—	100	—	60·3	62·7	13·9	14·1	1·3	4·5
—	6·4	—	—	—	100	—	55·8	—	—	—	68·0
—	1·85	Hydro-electric				—	16·2	—	—	—	—
1 027·30	1 262·96	—	—	—	—	9 010·3	11 079·5			1 799·6	2 449·9

§ 29 per cent of the energy generated in the Len-Energo district is supplied by the Volchov Hydro-electric Station.

attention was therefore concentrated on the development of stations burning peat and brown coal.

PEAT-BURNING POWER STATIONS.

A survey of the peat areas of the U.S.S.R. indicates that approximately 42 per cent of the world's peat resources are located in that country. The majority of this peat is in the northern districts of European Russia, and it is calculated that some 30 460 million tons of fuel (converted to tons with a calorific value of 7 000 calories/kg) are available south of the 60° latitude line. North of this line the vast peat resources of the tundra have as yet only been partially surveyed.

The first large-scale efforts to burn this fuel in district power stations dates back to 1914 when the Klasson power station, then known as Electro-Peridatch, was built at Bogorodsk, about 70 miles east of Moscow. The boiler-house efficiencies then obtained at this station were relatively low, and it was not until the Makarev shaft-chain grates were tried at the Shatura temporary station in 1920–1921 that boiler-house efficiencies were obtained which were comparable with those observed in the best coal-fired boiler practice.

The results obtained at the Shatura temporary station were sufficiently good to justify proceeding with a large station at Shatura, which now has an installed generating capacity of 136 000 kW. Fig. 3 shows a cross-sectional view of grates of this type recently built at the Dubrovka power station (100 000/200 000 kW) near Leningrad. It will be seen from this figure that the Makarev grate is a combination of a gas producer and a chain grate. The peat is fed down from the bunkers and whilst in the upper part of the furnace, which Prof. Makarev himself describes as the "shaft," heated air is forced through it and the peat becomes incandescent. At this stage its more volatile constituents pass through the openings in the rear arch into the main combustion chamber. Moisture in the peat is converted into water gas and also passes through and burns in the main combustion chamber. Tests have shown that with this type of grate the most satisfactory results are obtained with peat containing 32 per cent of moisture. Peat which has become excessively dry during the summer weather

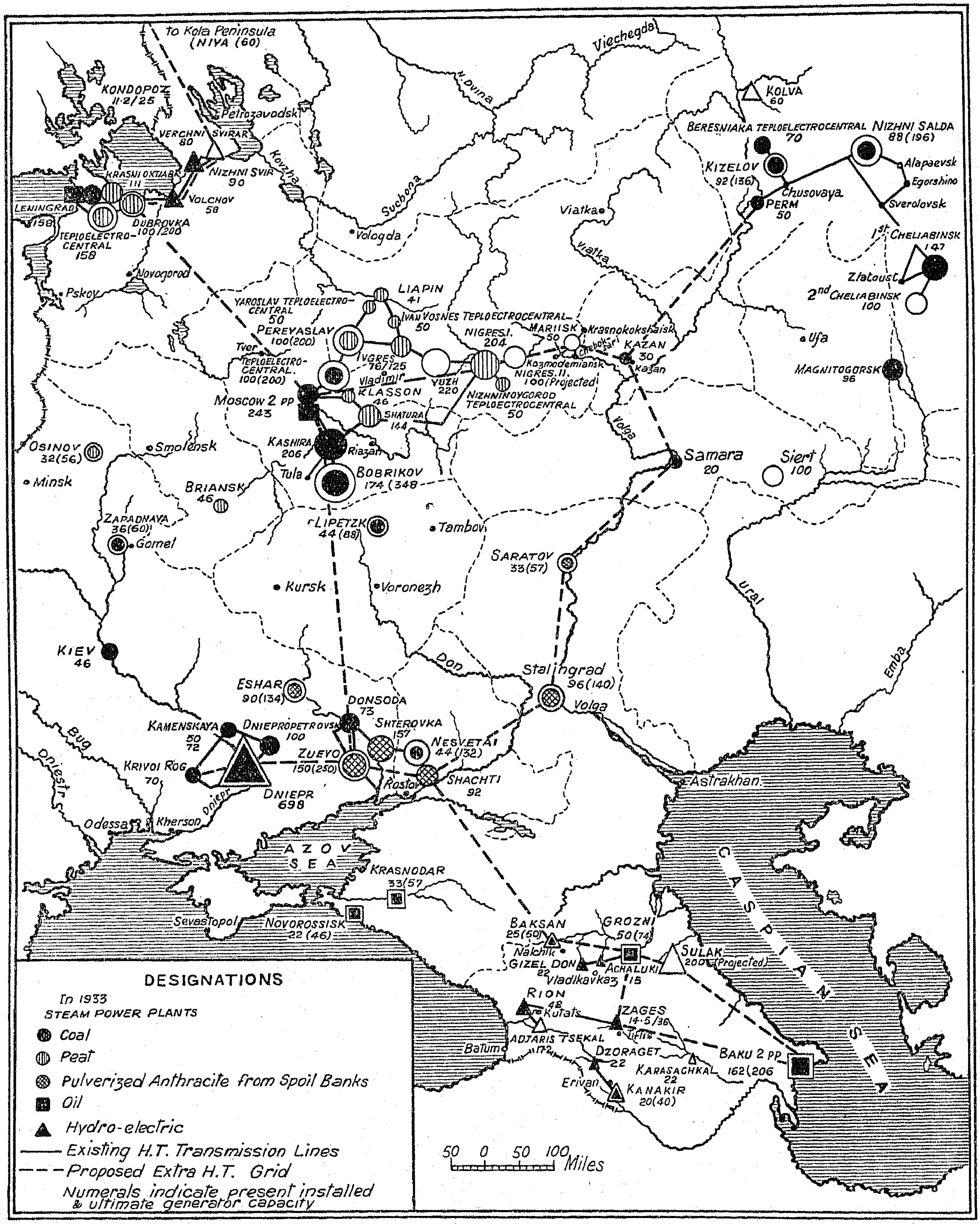

FIG. 2.—Map of outstanding electrical developments in the U.S.S.R.

is moistened in order that it may contain approximately this percentage of moisture when it is fed into the grates. The final burning of the peat takes place on the chain grate.

Almost simultaneously with the developments at Shatura the Krasni-October power station at Leningrad was put in hand; this station now has a total installed capacity of 111 000 kW. At Balakna in the Gorki (Nijni Novgorod district) the Gorgres power station was also proceeded with in 1923 and now has the distinction of being the largest peat-burning power station, with an installed capacity of 158 000 kW, which is being increased to 204 000 kW in the immediate future.

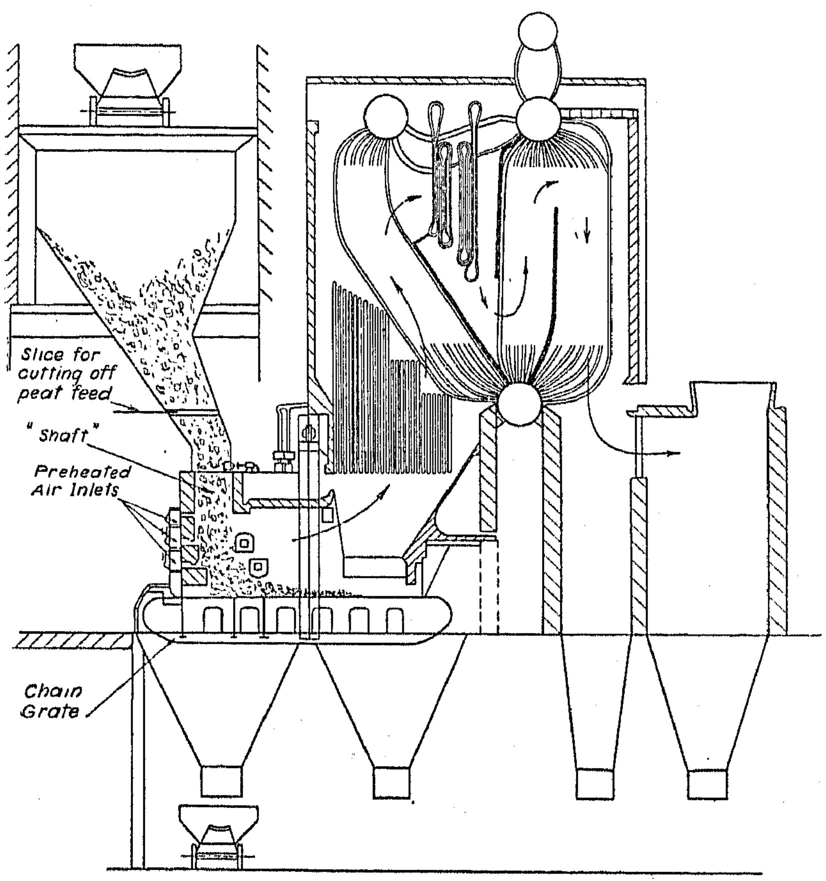

FIG. 3.—Makarev "shaft-chain" grate fitted to Stirling boiler.

The fuel-consumption figures obtained at Shatura power station burning air-dried machine-formed peat in the Makarev shaft-chain grate were as follows:—

Period of test	1 month
Actual weight of peat consumed	26 700 tons
Average moisture content ..	31·14 per cent
Average calorific value	3 478 calories per kg
Ash content	4·52 per cent
Average steam pressure	16 atmospheres at turbine stop valve
Average steam temperature ..	351° C.
Total quantity of steam generated	111 829 000 kg
Total quantity of steam to turbines	107 600 000 kg
Temperature of air leaving air heater	123° C.
Temperature of feed water leaving economizers	136° C.
Temperature of flue gases at base of smoke stacks after leaving air heaters	156° C.
Average evaporation	48·6 kg/m^2
Thermal efficiency of boiler plant	83·2 per cent

Table 3 gives a list of peat-burning power stations which are now in operation in the U.S.S.R., and also of those stations using this fuel which are intended to be proceeded with during the Second Five Year Plan. From this table it will be seen that at the present time peat provides one of the most important fuels in the U.S.S.R. Of the total installed boiler plant in the 81 stations reporting to Glavenergo—shown in Table 1 as 2 822 600 kW—approximately 30 per cent operate on peat fuel.

The original peat-burning power stations consumed machine-formed air-dried peat, i.e. peat which had been excavated from prepared bogs and had been passed through macerating machines in order to increase its density before being left exposed on the surface of the bogs to dry. The preparation of peat in this form, however, involved a very considerable amount of manual labour, as it was impossible to use mechanical excavators owing to the presence of roots and lignified trees in the bogs. Moreover, this labour was seasonal, because peat digging could only be commenced each year when the bogs thawed in the middle of May and could not be continued after the middle of August; otherwise the peat had not time to air-dry down to 32 per cent moisture before the winter frost began.

In order to reduce the amount of labour employed, a process of peat winning known as the hydro-peat process was developed. This consists of dislodging the peat in the bog with a high-pressure sluicing apparatus and then pumping the mixture of peat and water from the bog to specially-prepared drying-fields. When the peat on these fields is partially dry a special form of tractor with biscuit-cutter treads on its wheels is driven over the field, leaving the peat in such a form that after a few more days' air-drying it can be raked up easily and stacked for final drying in pieces of suitable size for use in power-station furnaces. Experience showed that this hydraulic method of winning peat had an advantage in price over the method employed for producing machine-formed peat; and several of the larger stations, including Gorgres, Krasni-October, and the recently completed Dubrovka station, work with hydro peat. The hydraulic method of winning peat is only possible during the period 15th May to 15th August.

Neither machine-formed air-dried peat nor that won by hydraulic methods has proved an entirely satisfactory solution of the fuel problem in the northern and central districts of the U.S.S.R. This has been due to climatic conditions and, to a certain extent, to labour difficulties. In 1933, for instance, the peat season was a serious failure in many districts, and certain important stations, including Shatura and Ivanovo-Vosnesensk, failed to win more than 30–50 per cent of the peat necessary to maintain them operating at their planned capacity. Wood, sawdust, coal, and crude-oil residue, were resorted to in order to keep many of the peat-burning stations in operation. Leningrad district imported large amounts of coal from the mines in Spitzbergen.

These shortcomings in the use of peat as a power-station fuel have led to a great amount of experimental work being done on the development of methods of winning and burning peat fuel in a form which can be won by mechanical means over longer periods of the

TABLE 3.
Power Stations in U.S.S.R. Burning Peat Fuel.

	Installed generating capacity in thousands of kW	
	On 1st Jan., 1933	Plan for 1937
Northern District		
Kotlas	—	36
Vologda	—	24
Archangel (T)	—	75
Oost-Vakshsk (T)	—	24
Onega (T)	—	24
Other stations (T)	—	12
Leningrad District		
Dubrovka	50	200
Leningrad (Krasni-October) ..	111	111
Leningrad (Mal. Narvsk) (T)	—	150
Leningrad (Okta) (T) ..	—	84
Cheripovetz (T)	—	25
Western District		
Briansk	22	47
Djarkovo-Svitetz	—	100
Other stations (T)	33	160
Moscow District		
Tver	—	50
Shatura	136	180
Bogorodsk (Klassov)	46	46
Riasan (T)	—	50
Tver thermal station	—	100
Ivanovo District		
Ivanovo-Vosnesensk	75	120
Yaroslavl	36	36
Youshov	—	100
Periaslavl	—	100
Other stations (T)	56	249
Nijni Novgorod (Gorki) District.		
Balakna (Gorgres)	158	204
Marieesk	—	100
Other stations (T)	48	207
Tartar Republic		
Koolegash	—	50
Other stations	20	30
White Russian Republic		
Osinov	20	72
Bueekov	—	72
Other stations (T)	52	266
Ural District		
Mid Ural	150*	150
Saldinsk	—	150
Southern Ural	—	75
Zakamsk (T)	25	100
Perm (T)	15	40
Other stations (T)	—	25
Far-Eastern District		
Habarovsk (T)	—	12
Tambov District		
Tambov (T)	—	48
Lgovsko-Mareetz (T)	—	24
Totals	1 053	3 628

...ed thermal and electric stations.

year. Equipment for dealing with what is known as "milled peat" has been put into satisfactory operation. Milled peat is peat which is obtained from specially prepared drained bogs by large revolving cutters so that the fragments of peat vary from dust to pieces approximately 20 mm in thickness. This peat cannot of course be burnt in a standard Makarev type of grate, and experiments have therefore been made with several modified forms of the Makarev type.

Interesting results have been obtained with a type of grate known as the Shirshnev grate. At the Briansk power station (22 000 kW) Shirshnev grates of the type shown in Fig. 4 have been put into satisfactory operation. In this type of grate, milled peat is fed in from the top of the combustion chamber and in its fall meets a flow of preheated air which keeps it in suspension until

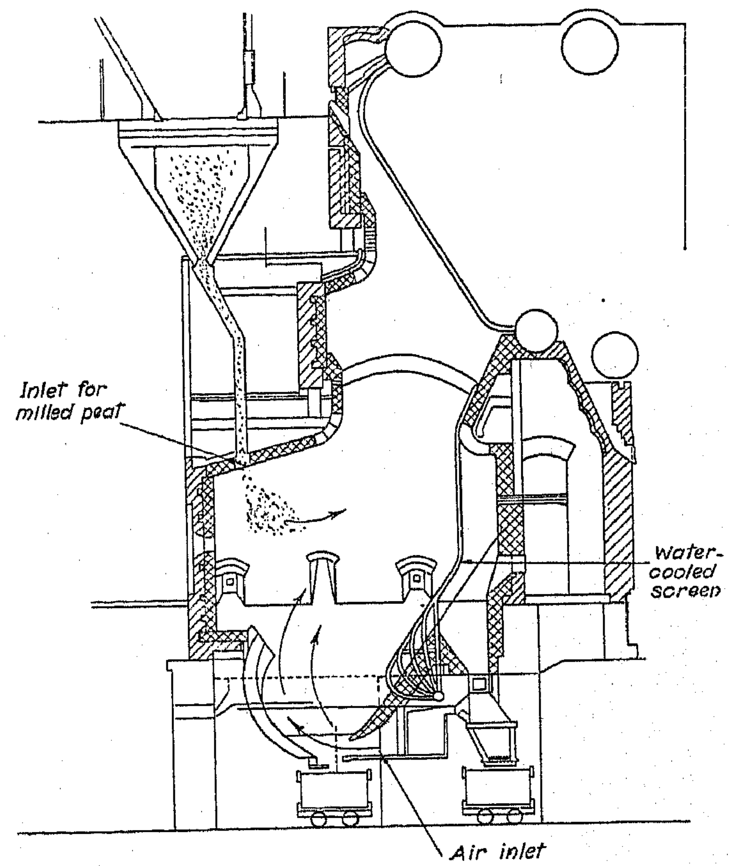

FIG. 4.—Shirshnev-type grate for burning milled peat.

combustion is complete. In the original furnaces of this type considerable trouble was experienced owing to slag forming on the back wall of the furnace; but in the more recent furnaces a water-cooled screen has been used in the position shown in Fig. 4, and this has apparently removed the difficulties due to slag formation. The most serious shortcoming of this grate is the difficulty of eliminating ash from the furnace. This shortcoming is, however, not regarded as an insurmountable obstacle to the extended application of the Shirshnev grate, and it is felt by the engineers of Glavenergo that this method of burning milled peat containing up to 50–52 per cent of moisture will be widely used. Neither the modified Makarev grate nor the Shirshnev grate is yet regarded as a final solution of the problem of burning milled peat, and many experiments are being conducted in various parts of the Soviet Union with the object of providing a more satisfactory grate. The relative ad-

vantages of using milled peat over machine-formed air-dried peat or hydro peat are apparent from Table 4.

Fig. 5 shows a recent development in which the wet peat from the bunkers is mixed with hot gases from the furnaces and, after being crushed into particles the size of grain, is carried with the hot gases through mixing and drying chambers to the furnaces, where it is burnt much in the same way as pulverized coal. This equipment is installed at Shatura power station on one boiler and is claimed to be giving satisfactory results,

Brown Coal.

Moscow has partially solved its power-station fuel problem by utilizing an extensive brown-coal deposit which lies about 60 miles south of Moscow. The Soviet Government have built a large power plant on this brown coalfield at Kashira (186 000 kW); and at the present time a very large chemical fertilizer plant, which will also supply a large quantity of power to the Moscow network, is under construction at Bobriki (200 000–400 000 kW) on this coalfield.

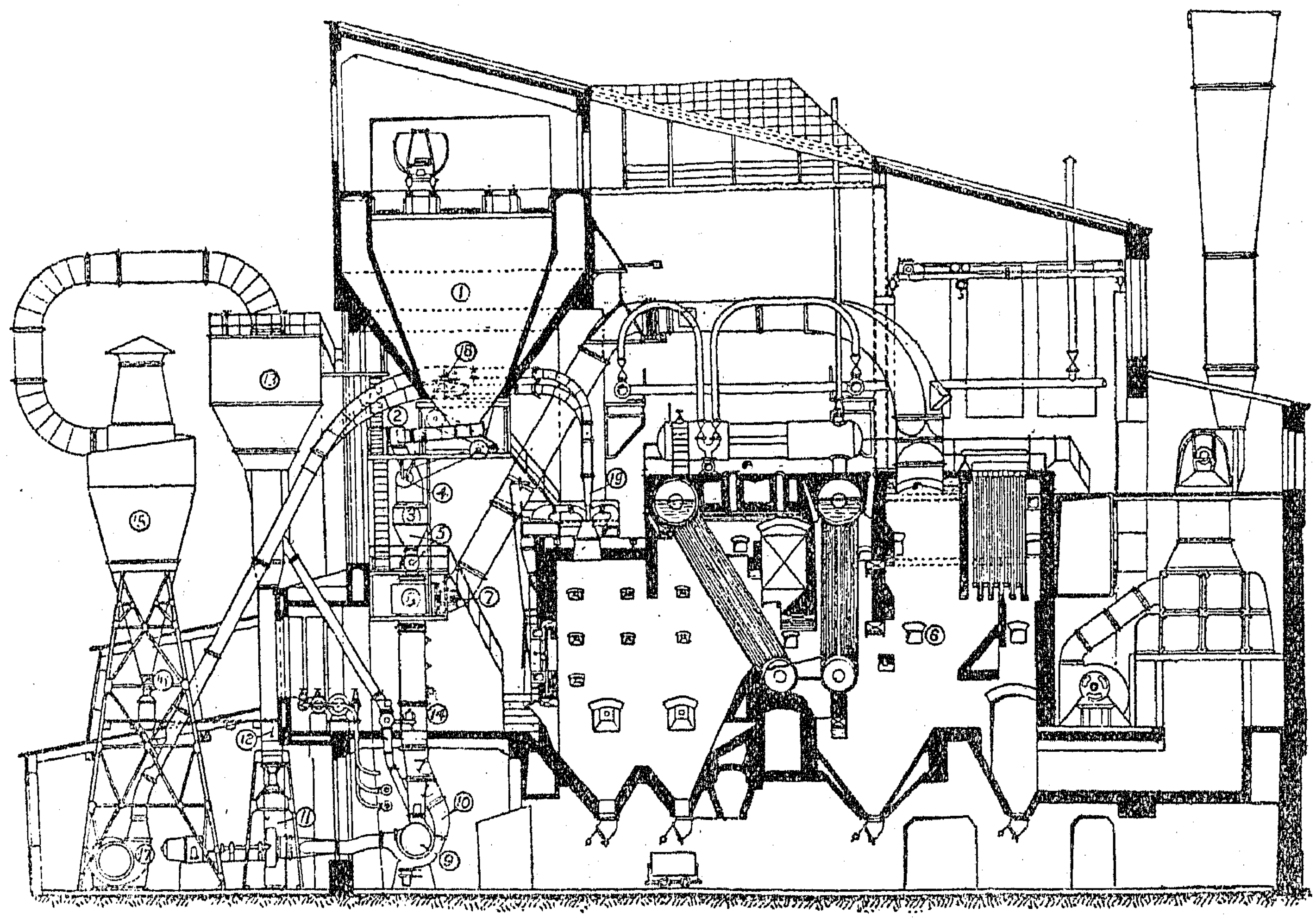

Fig. 5.—Cross-sectional view of a boiler house at Shatura, showing experimental equipment for pulverizing and burning milled peat.

but it must still be regarded as experimental. It indicates, however, the extraordinary amount of thought the Soviet authorities are giving to peat-burning problems.

Table 4.

Kind of peat	Approx. average moisture content	Cost at bunker, per ton	Number of employees
	per cent	Shillings (converted at 9·45 roubles to £1)	per ton
Machine-formed air-dried peat	35	30–40	2
Hydro peat ..	38	24–35	1·25
Milled peat ..	40	13–18	0·7

Anthracite Waste.

In the Ukraine and the mining districts of the Don basin, G.O.E.L.R.O. devoted their attention to utilizing the anthracite-waste spoil-banks which had accumulated over a period of many years in the coal-mining districts. The power stations at Shterovka (152 000 kW), Zuevka (150 000–250 000 kW), Stalingrad (51 000–140 000 kW), Saratov (22 500–57 000 kW), and Schacti (Artem) (66 000–92 000 kW), all of which have been put into operation during the last 10 years, are operated on pulverized anthracite-waste and are giving satisfactory results, although the thermal efficiencies obtained have not entirely fulfilled expectations.

Thermal-Electric Stations.

The building of new industrial cities and the rapid planned development of existing cities have provided an excellent opportunity for the introduction of schemes

involving the use of pass-out turbines, the steam from which is utilized for process work in factories and for raising the temperature of water for circulation over a wide area as a heating medium.

Large areas of the cities of Moscow and Leningrad are already heated with hot water circulated from the central power stations, and on the outskirts of these cities large new so-called thermal-electric stations are being built for heating the new residential districts. In Moscow the hot water leaves the water-heating plant in the central power station at a temperature, varying according to conditions, from 85° to 120° C., and after making a circuit of some two miles it returns at a temperature of 30°–35° C. The pipes are usually laid in special conduits in the streets and are lagged. This a bonded granulated cork insulation which gave good results. It was found that temperature-drops were experienced varying from 2·18 deg. C. to 6·36 deg. C. per km, with rates of flow varying from 1·205 to 0·176 metres per sec. It is considered practical to increase the flow rate to 1·5 metres per sec., in which case it is calculated that the temperature-drops per km will fall to less than 1 deg. C. with a natural earth temperature of approximately 5° C. at the depth at which the pipes are laid.

Later sections of the Leningrad network have employed 10-in. pipes laid in pumice-stone concrete. This construction was found cheap and did not suffer from the disadvantage, which had been one of the shortcomings of cork insulation, of absorbing moisture during the

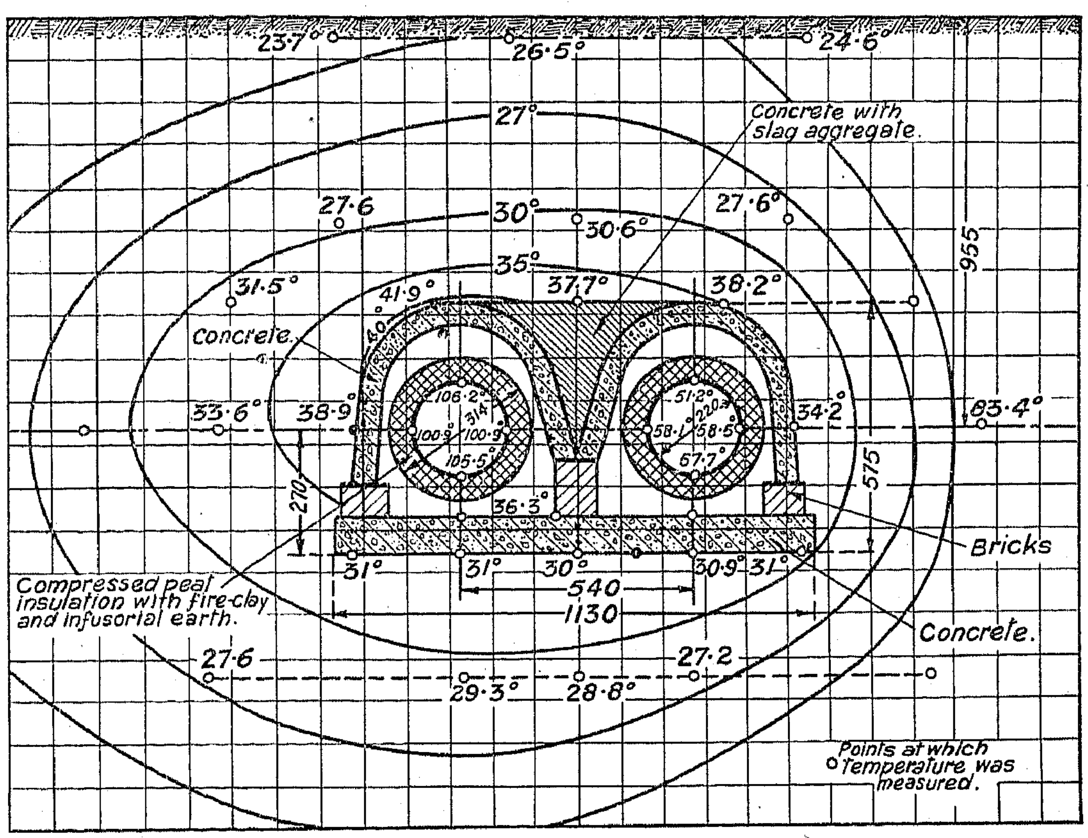

FIG. 6.—Heat distribution around insulated pipes conveying hot water underground for heating buildings. (Distances in millimetres.)

lagging is composed of segments of compressed peat fixed into position with a mixture of fireclay and infusorial earth. The protecting conduits are formed of cement made with aggregates in which slag and pumice stone are frequently used to improve the heat insulation.

Fig. 6 is a diagram of the heat distribution round a hot-water-carrying pipe insulated in this manner. In many cases the special arched conduit has been abandoned in favour of simply burying the pipes in cement made with pumice stone.

In Leningrad, exhaustive experiments have been made during the years 1926–1934 with the object of determining the most satisfactory insulating media for hot-water circulating systems and also to ascertain the optimum rates of flow that should be employed in hot-water circulating pipes.

In laying the earlier part of the Leningrad heating network 8-in. to 10-in. pipes were employed insulated with spring floods. The following figures show the kind of result obtained:—

Internal diameter of pipe ..	253 mm
Insulation	Pumice-stone concrete, thickness about 85 mm
Depth in earth	1·2–1·5 metres
Natural earth temperature, at date of tests	1·9° C.
Length of pipe tested ..	470 metres
Difference in temperature between outgoing and incoming water	40 deg. C.
Average water temperature ..	99·8 deg. C.
Rate of flow of water ..	0·124 metre per sec.
Drop of temperature per kilometre	8·26 deg. C.
Equivalent drop calculated for a rate of water flow of 1·5 metres per sec. .. .	0·684 deg. C.

Calculated loss of heat per km at rate of flow of 1·5 metres per sec. .. .. .. 1·7 per cent

The power produced in these thermal-electric stations is, of course, fed in to the local network.

The actual quantities of heat distributed by hot water in Moscow and Leningrad still fall far behind those of New York, which in 1930 distributed approximately 3 500 mega-calories. The Moscow system distributes approximately one-quarter of this amount, and the hot-water heating load on the Leningrad power stations is approximately 350 mega-calories.

TABLE 5.

Thermal-Electric Power Stations in the U.S.S.R. with Installed Generating Capacity Exceeding 10 000 *kW.*

	Installed generating capacity
	kW
In Operation on 1st January, 1933	
New Beresniki (chemical combine) ..	83 200
North Don soda and chemical combine ..	64 000
Kuznetzsk steelworks	48 000
Gorki (Nijni Novgorod) automobile factory	24 000
Grosni oil-fields	25 000
Harkov tractor works	15 000
Old Beresniki (chemical combine) ..	12 000
In Course of Construction	
Yaroslavl rubber, asbestos, and textile combine	77 000
Moscow [Thermo-Technical Institute: high-pressure (130 atmospheres abs., 1 905 lb. per sq. in. gauge) station] ..	60 000
Harkov (Krasnozavodski station).. ..	60 000
Moscow (Stalin station)	50 000
Voronesh thermal-electric station ..	50 000
Tula thermal-electric station	50 000
Izevsk thermal-electric station	48 000
Nijni Tagil thermal-electric station ..	50 000
Kazan thermal-electric station	44 000
Krivoi Rog thermal-electric station ..	25 000
Leningrad meat combine	12 000
Stalingrad tractor works	12 000
Kiev thermal-electric station	12 000
First Moscow thermal-electric station ..	12 000
Second Moscow thermal-electric station ..	12 000

Many of the large new industrial towns are being built with the idea of all their buildings being heated from central thermal-electric power stations. Table 5 contains a list of those thermal stations which are already in operation, and also of those which it is anticipated will commence operation during the present year.

The plant at the Beresniki Chemical Works in the North-West Ural district is not unlike that which has attracted British engineers' attention to the Billingham works of Imperial Chemical Industries, Ltd., and it may be taken as typical of several similar plants now being built in the U.S.S.R.

At Beresniki the boiler plant consists of three Babcock and Wilcox boilers and two Hannomag boilers. All the boilers are similarly rated and have an evaporating capacity of 120 metric tons per hour at a pressure of 61 atmospheres abs. (885 lb. per sq. in. gauge) and a temperature of 450° C. The fuel used is pulverized coal from the neighbouring Kizel coalfield.

There are three high-pressure pass-out turbo-alternator sets each having an output at the generator terminals of 12 800 kW, and one house high-pressure turbo-alternator set with an output of 6 400 kW. The turbines for the 12 800-kW sets are rated for steam at 56 atmospheres abs. (812 lb. per sq. in. gauge) and 435° C., and pass out at 17·5–19 atmospheres abs. (242–264 lb. per sq. in. gauge) and a temperature of 290°–305° C. Each of them is designed to deal with 191 metric tons of steam per hour, and the 6 400-kW machine is calculated to pass out 100 metric tons of steam under the same conditions of pressure and temperature.

With two 12 000-kW sets and the house set in operation the total quantity of pass-out steam from the high-pressure turbines is 482 metric tons per hour, of which approximately 128 metric tons is fed to the chemical plant for process purposes.

Some 52–55 metric tons of the pass-out steam at 17·5 atmospheres abs. (242 lb. per sq. in. gauge) and 290° C. is conveyed to the feed-heating and de-aerating equipment. The remaining 300 metric tons is reheated to 375° C. and then passed to the low-pressure turbines. These consist of three 12 800-kW turbo-alternator sets and three 3 300-kW d.c. turbo-generator sets. The turbines of all six sets are built for taking steam at 16 atmospheres abs. and 360° C. The 12 800-kW sets are designed to give a steam consumption of 4·65 kg (10·25 lb.) per kWh when working as straight condensing sets with cooling water at 15° C. When passing out 9 metric tons of steam per hour at 6·7 atmospheres abs. (84 lb. per sq. in. gauge) and 12 metric tons per hour at 3·2 atmospheres abs. (32·5 lb. per sq. in. gauge), the guaranteed consumption is 5·9 kg (13 lb.) per kWh.

The guaranteed net overall thermal efficiency of this station is 58·7 per cent, after making allowance for the power consumed by the station auxiliaries. This plant has now been in operation for nearly two years and, although several "teething" troubles have been encountered, is apparently regarded as satisfactory in general operation.

In the Moscow district the first Moscow thermal-electric station, which was erected at the Tege fine chemical works, provides an interesting example of a smaller installation of the same kind. Fig. 7 shows the thermal régime of this station and is self-explanatory.

Another exceedingly interesting installation is the new thermal-electric station now being completed in Moscow. It is equipped with two Loeffler-type boilers manufactured by Messrs. Witkowitz in Czecho-Slovakia. These boilers are each capable of delivering 130 metric tons of steam per hour at 130 atmospheres abs. (1 920 lb. per sq. in. gauge) and 500° C. The boilers can be forced to supply a maximum of 150 metric tons of steam per hour over long periods. A third boiler is being built in the U.S.S.R. The available maximum steam-raising capacity of the boiler house has been regarded as 300

metric tons per hour, and consequently 24 000 kW was chosen as the most suitable size for the high-pressure turbo-alternator set. The high-pressure turbine has been manufactured by the Metropolitan-Vickers Electrical Co., Ltd., for a steam pressure of 125 atmospheres abs. (1 828 lb. per sq. in. gauge) and 470° C., passing out steam at 27 atmospheres abs. (382 lb. per sq. in. gauge).

The low-pressure generating plant for this station consists of two dissimilar turbo-alternator units, one of 24 000-kW capacity and the other of 12 000-kW output. The 12 000-kW set is designed to pass out 100 metric tons of steam per hour at 5 atmospheres abs. (59 lb. per sq. in. gauge).

Fuel Consumption.

During recent months Glavenergo have made a very definite attempt to reduce the fuel consumption per kW output of their stations. Economies have been effected in every possible direction, and returns for the first quarter of 1934 show that the average fuel consumption per kWh output of the 81 steam stations they are operating has now been reduced to 0·7 kg (1·55 lb.), whereas in 1932 the figure was as high as 0·79 kg (1·76 lb.). These figures are corrected so that they correspond to fuels having a calorific value of 7 000 calories per kg.

Hydro-Electric Developments.

With the exception of the Ural Mountains and the Caucasus, both of which are far removed from the central industrial areas of the European part of the U.S.S.R., there does not exist sufficient hill country to make high-head hydro-electric stations possible.

On the other hand the Soviet Government have decided to build a series of large low-head hydro-electric stations on the great rivers of European Russia, which are being developed to form the basis of a comprehensive inland-water transport system. The dam built on the Dnieper, and those now in hand on the Volga and the Svir, are being built with a dual object, namely of providing cheap electric power and of making the river navigable for large vessels. Even the Volhov dam, built in 1922–26, is to form a link in the canal system connecting the Baltic with the Dnieper and the Black Sea. The Kamishenski dam on the Lower Volga is primarily destined to supply power for irrigating 8 million acres of the rich soils lying to the east of the Volga. The water will be pumped from the river itself by 59 pumping stations having a total installed pump-motor capacity of 1 244 015 kW. The largest pumping station will deliver approximately 500 000 cub. ft. of water per minute against a head of 190 ft. The motors at this station will develop a total of 213 500 kW. Vertical pumps will be employed, and it is suggested that each of these should have a rating lying between 45 000 and 75 000 h.p. These figures are quoted from the preliminary plans of the Central Planning authorities recently published in Moscow, in order to give some idea of the magnitude of the Lower Volga irrigation scheme.

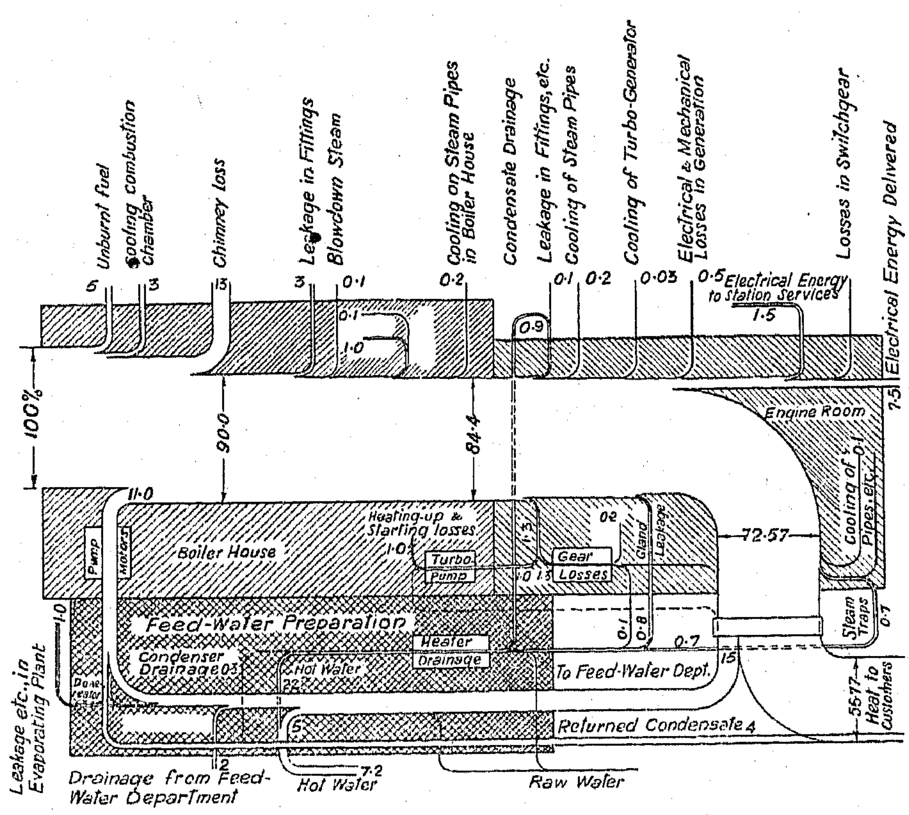

FIG. 7.—Thermal régime of steam plant at Tege chemical works near Moscow.

Volhov Hydro-Electric Station.

The first of the hydro-electric power stations to be built was that on the Volhov River, where the level of the water has been raised to give an operating head at the turbines of 10·5 metres. The turbines are of the Francis type, are calculated for a flow of water of 80 cubic metres per sec., and an output of 10 000 h.p. There are eight such main turbines and two house

turbines each of 1 400 h.p. The Volhov power plant feeds into the Leningrad network, and statistics show that in 1932 its total output was 439 900 000 kWh. The station was built during the most difficult years the Soviet régime has experienced, and it is not surprising to find that the total cost—including 80 miles of transmission line, a main step-down substation, and a series of seven secondary substations—was nearly £12 000 000. In Russian hydro-electric stations the period of low water occurs during the end of the winter before the snow commences to melt, and it may be of interest to note that during 1928 and 1929, before the extensions to the peat-burning station at Krasni-October were completed and when Leningrad was threatened with a shortage of power, the operating authorities succeeded in tiding over the low-water period by freezing a lip of ice on to the top of the concrete dam, thus raising the water-level to an extent sufficient to increase the station output appreciably during the later part of the winter.

Svir River Hydro-Electric Scheme.

The Svir River running between Lakes Onega and Ladoga forms an important link in the White Sea and Baltic Inland Waterway, which was officially declared open for shipping traffic in July 1933. Ultimately it is proposed to dam this river in three places, but for the present one dam only has been completed. The hydro-electric power station erected at this dam was to be put into service during the autumn of 1933. In this station four 37 500-h.p. vertical Kaplan-type turbines working with an average head of 11 metres and with a speed of 75 r.p.m. have been installed. There are also two house sets of 2 600 h.p. It is estimated that when the three Svir stations are completed their average annual output will be 550 million kWh. Three of the turbines were built by Messrs. Verkstaden Kristineham in Sweden, but the fourth turbine was built in the U.S.S.R. The bulk of the electrical equipment is also being made in the U.S.S.R. Considerable trouble was experienced in getting a foundation for the dam at this station; Fig. 8 shows a cross-sectional view of the rather exceptional construction ultimately adopted.

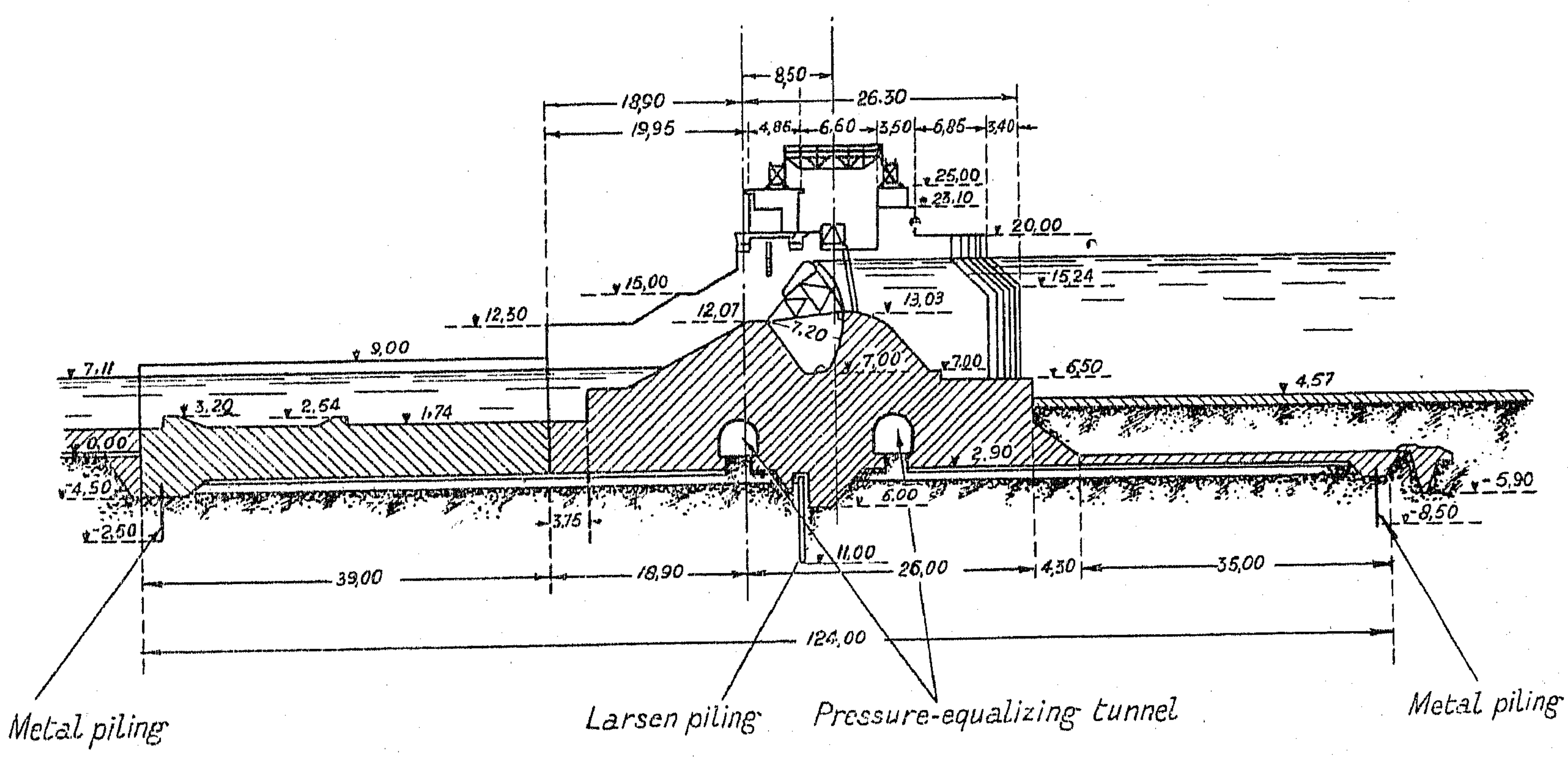

FIG. 8.—Cross-section of Svir Dam.

Dnieper Hydro-Electric Station.

By far the most important of the low-head hydro-electric stations yet completed is the Dnieper station. The Dnieper dam has a length of 760·5 metres and a height to the top of the dam of 42·25 metres. The width at the base of the dam is 39·7 metres. The dam is divided into 47 sections, each section being closed with a Stone-type gate 13·86 × 9·7 metres in area and weighing 42 tons.

The available head of water for the turbines is 35·5 metres. Nine vertical Francis-type turbines, each rated at 94 700 h.p. and running at 88·25 r.p.m., are installed. The turbines are coupled to generators with an output of 77 500 kVA at a power factor of 0·8. The generating voltage is 13 800, which is stepped up to 161 000 volts for transmission to the works of the Dnieper combine and for feeding the Central Ukranian network. Each generator is provided with a house generator of 750 kVA feeding direct to the station 2 300-volt auxiliary supply system.

Zemcho-Avchal, on the Kur River.

This station is for supplying the town of Tiflis and, although it will ultimately be extended to 36 000 kW, its present generating equipment consists of four vertical Francis-type turbines driving generators rated at 3 600 kW. The average head is 20 metres.

Rion Hydro-Electric Station, on the Rion River.

The Rion hydro-electric station operates with a head of 10 metres. Four sets are installed employing vertical Francis-type turbines each rated at 17 200 h.p. Although the installed generating capacity of this station is 48 000 kW, at times of low water the available output may fall to 10 300 kW. The annual output will be approximately 240 million kWh.

Niva Hydro-Electric Scheme.

Plans have been made to utilize the Niva River for supplying power to the Apetate mining district on the Kola Peninsular. Three hydro-electric stations are to be built, but only one has so far been proceeded with. The station lies north of the Arctic Circle in latitude 67°, and has the distinction of being the farthest north hydro-electric station. The available head is 37 metres. There are four Francis-type turbines of Russian manufacture driving generators each rated at 15 000 kW and running at 187·5 r.p.m.

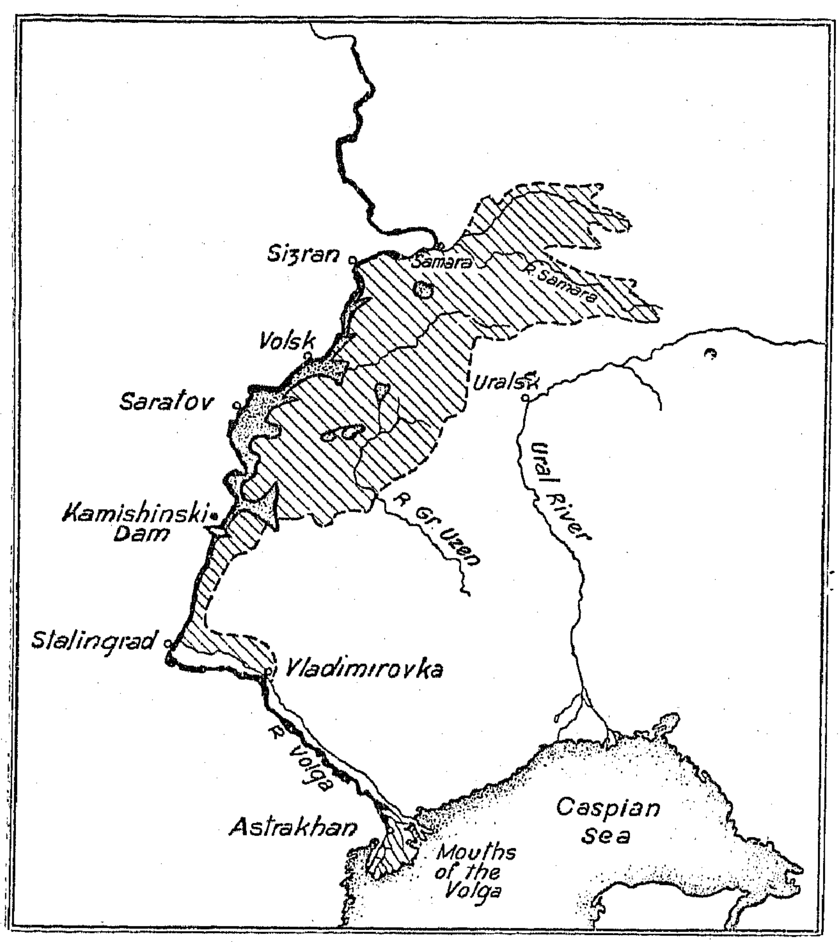

Fig. 9(a).—Map of Lower Volga showing area which will be irrigated when the Kamishinski Dam Scheme is completed.

Kondopog Hydro-Electric Station.

This station supplies energy to Karellia and the town of Petrozavodsk. Two horizontal-type turbines rated at 5 700 h.p. are installed, and it is proposed to extend the station by installing four more similar machines or two large turbines, giving the station an ultimate capacity of approximately 25 000 kW.

Middle Volga Hydro-Electric Scheme.

Work is now being commenced on three large hydro-electric stations on the Middle Volga. According to a decree published on the 23rd March, 1932, the three stations are to be situated as follows: one near Yaroslavl for supplementing the Ivanovo Vosnesensk network; one at Balakna for supplementing the Gorki (Nijni Novgorod) network; and one on the Kama River near Perm for supplying power into the Mid Ural system. Details of these stations are not yet available, but it is stated in the decree that their aggregate capacity will be 800 000–1 000 000 kW. The heads employed will be of the order of 20 metres.

Kamishinski Dam on Lower Volga.

This undertaking, to which reference has already been made, is to be proceeded with during the Second Five Year Plan. The general plan of this colossal scheme is shown in Figs. 9(a) and 9(b). The power station which the Soviet engineers now have in view will be considerably larger than the Dnieper station. It will probably be of an open-air type, and 20 generating sets, each capable of delivering 60 000 kW, will be installed immediately. Ultimately additional sets will be added, bringing the total generating capacity of the station to 1 560 000 kW. Kaplan turbines will be employed, running at 107 r.p.m. The generating voltage will be 13 800, and the generators will be grouped in pairs supplying transformers stepping up to the transmission voltage, which will be 220 kV. It is estimated that the scheme will take nine years to complete.

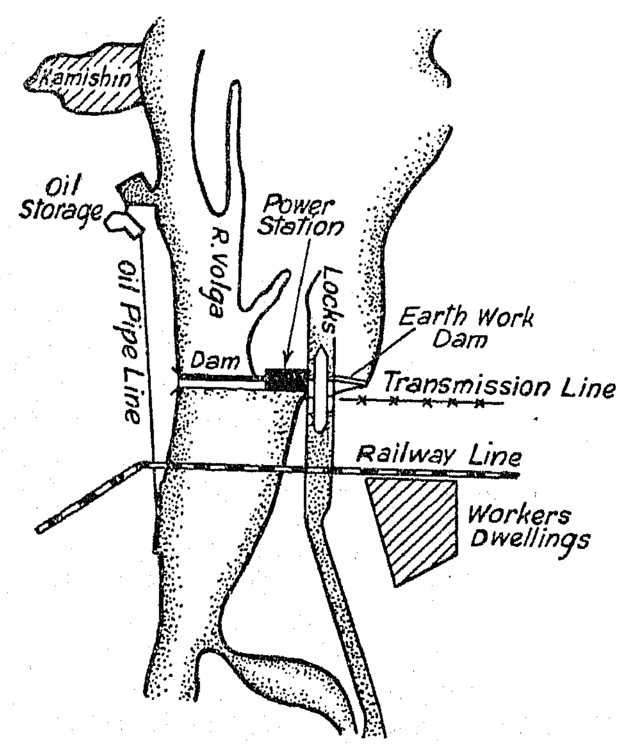

Fig. 9(b).—Plan of proposed Kamishinski Dam.

High-Head Hydro-Electric Stations.

Glavenergo and the organization which preceded its formation embarked upon the building of a number of high-head hydro-electric stations in the mountainous districts of the Caucasus and Central Asia. The stations already completed and in operation are the following:

Kanakir Hydro-Electric and Irrigation Scheme.

This hydro-electric and irrigation scheme is calculated to play an important role in the development of Armenia. The station has a working head of 170 metres. Two Francis-type turbines each of 15 000 h.p. are now installed, and two further machines of 48 000 h.p. are to be added at a later date.

Dzoraget Hydro-Electric Station.

This station also feeds on to the Armenian network and works with a head varying from 99 to 114 metres. The present equipment comprises three 10 500-h.p. Francis-type turbines, driving generators each rated at 7 250 kW.

Adjaris-Tsekhal Hydro-Electric Station.

After experiencing considerable difficulties with faulty rock, this plant, situated on the frontier between Turkey and the U.S.S.R., has now been completed and supplies Batum. The equipment at present installed is rated at 23 500 h.p. The estimated annual output will be 105·3 million kWh.

Leninakan Hydro-Electric Station.

This station lies on the Arpatchi River and works with a head of 110 metres. There are five Russian-built Francis-type turbine sets running at 750 r.p.m., each delivering 1 500 h.p. The bulk of the power generated is fed into the Armenian network.

Giseldon Hydro-Electric Station.

This is one of the few Pelton-wheel stations in the U.S.S.R. It is equipped with three 7 500-kW sets and works with a head of 312 metres. The station supplies the town of Ordjanikidse (Vladikavkas) on the northern side of the main Caucasian range.

Ulba Hydro-Electric Station.

The Ulba hydro-electric station is the first of a number of stations in Central Siberia. It is equipped with three 13 000-h.p. Francis-type turbines working with 155-metre head. The power generated is supplied to the Ridder Zinc Mines.

Chirchik Hydro-Electric Station.

One of the most important developments in Central Asia at the present time is the Chirchik Fertilizer Works, designed to produce large quantities of nitrate fertilizer for the cotton-fields of Central Asia. Two hydro-electric stations are to be built, one 7 km lower down the river than the other. The No. 1 station, now being commenced, will be an open-air station with four Francis-type turbines working with a head of 66 metres. Each turbine will develop 60 000 and be coupled to a 53 000-kW alternator. The No. 2 station will have four sets each developing 40 000 h.p.

The scheme also provides for irrigating some 1 250 000 acres of cotton-growing land. This station will work in parallel with steam stations at Chemkent and Tashkent. It is interesting to note that the Soviet authorities have called in Italian consulting engineers to lay out the hydro-electric side of this great scheme.

TABLE 6.

*Output Figures of 10 Glavenergo Generating Stations for the Year 1932.**

	Total installed capacity (in thousands of kW), 31st Dec., 1932	Average installed capacity (in thousands of kW) during 1932	Maximum load, in thousands of kW	Annual number of hours on maximum load	Average load, in thousands of kW	Load factors: Average load as a percentage of maximum demand	Load factors: Average load as a percentage of average installed capacity	Total power generated, in millions of kWh	Heat supplied to customers, in mega-calories	Notes
First Moscow station	107·5	107·5	110·7	3 980	50·4	45·0	46·6	439·6	55·319	Oil fuel
Shatura power station, near Moscow ..	136·0	136·0	141·9	5 250	85·0	60·0	62·4	745·8	—	Peat fuel
Orechovo Zuevo thermal-electric station	8·6	8·6	9·6	4 120	4·5	47·0	52·3	39·5	97·210	Peat fuel
Krasni-October station, Leningrad ..	111·0	111·0	105·4	4 260	51·5	49·0	46·3	451·4	4·326	Peat fuel
Ivanovo Vosnesensk station	75·0	63·0	37·6	4 160	17·8†	47·0	28·3	156·6	4·200	Peat fuel
Chliabinsk power station	99·0	85·0	61·1	5 400	39·2	64·2	46·2	345·2	—	Coal
Gorki (Nijni Novgorod) power station	158·0	154·2	91·0	5 740	59·6	66·0	38·8	535·2	15·445	Peat fuel
Shterovka power station	152·0	152·0	93·5	4 800	51·3‡	55·0	33·6	448·6	—	Pulverized anthracite from spoil banks
Zuevka power station	150·0§	141·7	88·0	4 500	45·0	51·0	31·8	395·6	—	Pulverized anthracite from spoil banks
Baku Red Star station	85·0	87·0	73·9	5 700	48·0	65·0	54·5	420·7	—	Oil fuel

* Figures extracted from official returns published in *Electricheski Stanzi*, No. 6, 1933.
† The low average load on this station was due to absence of demand, resulting from shortage of raw materials in the cotton manufacturing industry.
‡ The low load-factor on installed plant was largely due to shortage of circulating water, following trouble with the dam of the artificial lake from which it was taken.
§ This station only went into service in December, 1931, so that these figures represent the first year of its operation, including test work, etc.

OUTPUT FIGURES OF GLAVENERGO STATIONS.

Glavenergo make a practice of publishing annually details of the output figures of the power stations which come under their control. For the year 1932 these figures were published in a Bulletin the full text of which is given in *Electricheski Stanzi* No. 8, July–August, 1933.

Table 6 has been prepared from these official figures, and it clearly shows the extent to which the stations in the Moscow area were overloaded in 1932. At this time the electric supply authorities were compelled to engage in special propaganda to curtail the use of electricity for lighting and domestic purposes in many districts. In November, 1932, the lighting authorities in Moscow forced economies by ordering that customers would be charged double (and in some cases more than double) rate for all units shown on their meters each month in excess of two-thirds the amount they had used in November, 1932. At the same time the municipal authorities in the city made extensive improvements in the street lighting of the city, and this load and the traction load were greatly increased. The completion of the new thermal-electric power stations and of the Bobriki station will go far towards alleviating the gravity of the situation.

Table 7 gives some idea of the generating costs in seven districts of the U.S.S.R. The average cost per kilowatt-hour is shown as 5·768 copecks, which, taken at the average official rate of exchange ruling in 1932, is equivalent to approximately 1d. per unit. As is well known, however, this official rate of exchange bears little or no relationship to prices within the territories of the U.S.S.R.; consequently the true equivalent of 5·768 copecks in purchasing value in the U.S.S.R. in

TABLE 7.

Generating Costs, in Copecks per kWh.

District authority	Fuel	Wages and social insurance, etc.	Sundry costs	Interest and depreciation	Actual total cost	Estimated cost according to plan
Moscow	3·040	1·120	0·960	0·860	5·980	5·37
Leningrad	2·914	1·325	0·902	1·017	6·158	6·40
Donbasin	1·015	0·939	1·933	0·954	4·841	4·30
North Caucasus	1·090	1·176	2·033	0·921	5·220	5·00
Gorki (Nijni Novgorod)	3·837	1·131	1·248	0·699	6·915	—
Ural	1·770	1·700	0·510	0·920	4·900	4·80
Western Siberia	1·688	1·591	4·694	0·919	8·892	—
Averages	2·459	1·189	1·247	0·873	5·768	—

TABLE 8.

*Nominal Rating and Output of Turbo-Generators.**

Nominal output of generator	Nominal power factor	Nominal maximum continuous output of turbo-generator	Ratio of economical to nominal maximum output	Nominal speed	Minimum voltage at terminals of stator windings			
kVA		kVA		r.p.m.	volts	volts	volts	volts
940	0·8	750	0·8	5 000/1 000	400	525	3 150	6 300
1 875	0·8	1 500	0·8	5 000/1 000	400	525	3 150	6 300
3 125	0·8	3 500	0·8	5 000/1 000	—	525	3 150	6 300
5 000	0·8	4 000	0·8	5 000/1 000	—	—	3 150	6 300
7 500	0·8	6 000	0·8	3 000	—	—	3 150	6 300
15 000	0·8	12 000	0·8	3 000	6 300	10 500	—	—
31 250	0·8	25 000	0·8	3 000	6 300	10 500	—	—
58 900	0·85	50 000	0·8	3 000	—	10 500	—	—
55 560	0·9	50 000	0·8	1 500	—	10 500	—	—
111 111	0·9	100 000	0·8	1 500	—	—	15 000	—
222 222	0·9	200 000	0·8	1 500	—	—	—	(22 000)

* Turbo-generators sets of outputs up to and including 6 000 kW are to be combined sets, i.e. with condenser and turbine (5 000 r.p.m.) as one unit on common bedplate with gears and generator (1 000 r.p.m.), etc.

1932 can be regarded as between 0·25d. and 0·35d. The last column in Table 7 shows the costs which the authorities in the areas named estimated they could work to at the commencement of the year under review, and which figured in the Control Figures of the State Planning Authorities.

Steam Power-Station Design.

When the Soviet authorities embarked upon their building programme considerable controversy arose as to the most satisfactory lay-out for large steam power-stations. It must be borne in mind that practically nowhere in the U.S.S.R. does economy of space play any serious part except in such places as Shatura, where the area of the sand outcrop lying between two lakes in a peat-bog district made it necessary to arrange the station so that all the main foundations could be in the sand itself.

There have been three distinct tendencies in steam-station lay-out. In the first place there is the lay-out adopted at Shatura, where three separate boiler-houses have been built at right angles to the engine room. In this case the switchgear and transformers are arranged on the opposite side of the engine room to the boilers.

Secondly, there is the so-called Krasni-October design favoured by the Leningrad engineers. In this design the boilers are arranged in two boiler houses, one on each side of the engine room. The 111 000-kW Krasni-October and the 200 000-kW Dubrovka stations have been built in this way. This arrangement, which was primarily dictated by the necessity of handling large volumes of peat fuel, has obvious advantages from the steam engineer's point of view, but its chief drawback lies in the fact that the switchgear and transformers have to be arranged either at the end of the engine room or away from the station, with a boiler house intervening. This necessitates an excessive expenditure in connections between the generators and the step-up transformers. Alternative arrangements have been suggested in which the transformers are in bays between the groups of boilers or in which the switchgear is on the roof. Fig. 10 shows a cross-section of the Dubrovka station.

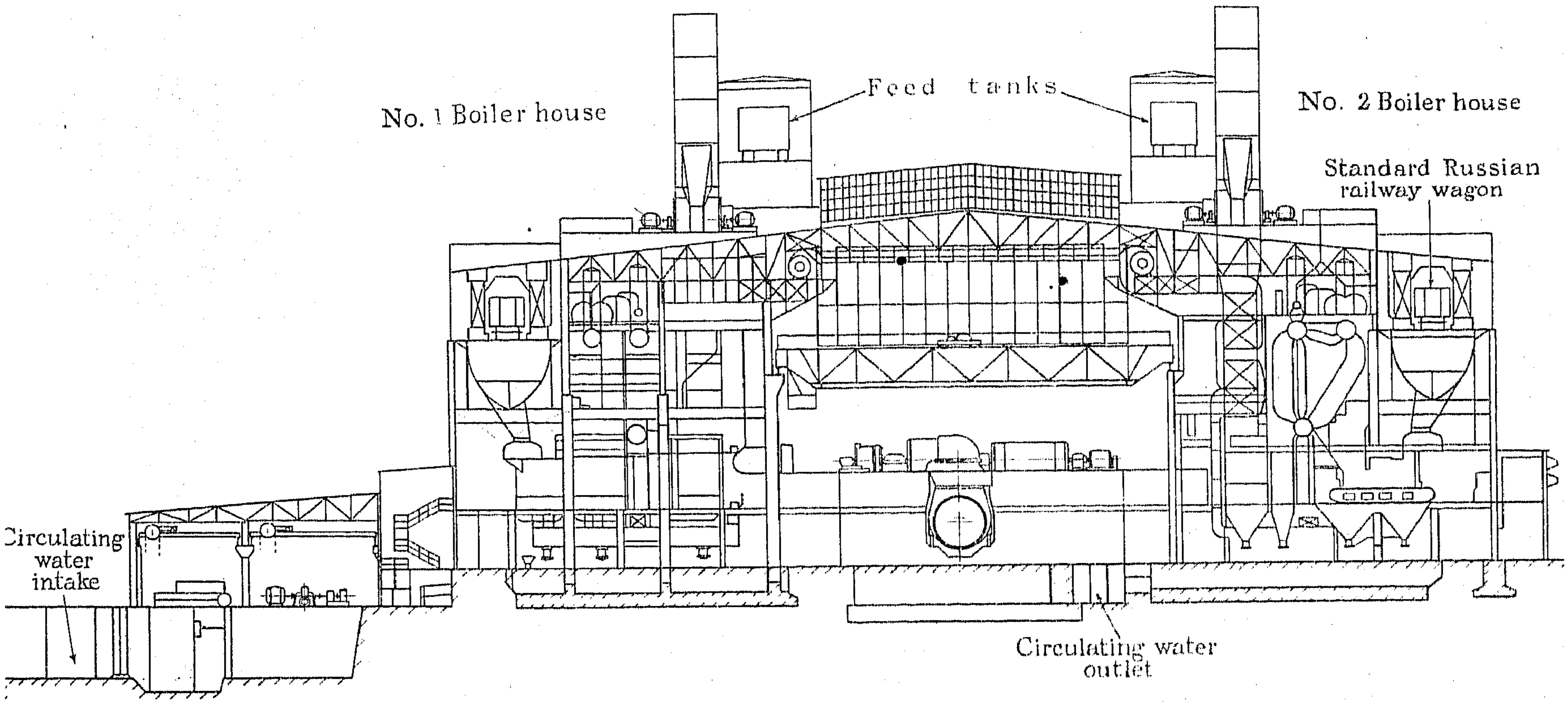

Fig. 10.—Cross-section of Dubrovka power station.

The type of station now generally adopted by the Glavenergo authorities, and originally due to Prof. Polivanov, is that shown in Fig. 11. This illustration shows the station now under construction at Bobriki for supplying Moscow. This station will have an output of 200 000 kW, but has been built with the idea of increasing its output to 400 000 kW. As already stated, the fuel used in this case is to be brown coal (lignite). The stations at Shterovka (152 000 kW), Balakna (Gorgres) (156 000–204 000 kW), Cheliabinsk No. 1 (150 000 kW), Zuevka (150 000–250 000 kW), Ivanovo-Vosnesensk (75 000–125 000 kW), and Stalingrad (51 000–140 000 kW), are all built on this principle. Zuevka station is the most recently completed of the stations named, and is serving as a standard for some four other stations of similar type now being proceeded with, namely Youzhov (near Gorki), Mid Urals, Nesvetai, and Kamenka.

Standardization of Equipment.

The Zuevka type of station having become more or less standardized, it is perhaps not surprising that the Soviet authorities have made a definite attempt to standardize power-station equipment in every way possible.

Generating and transmitting voltages were standardized from the outset, but during the last two years definite attempts have been made to standardize power-plant equipment.

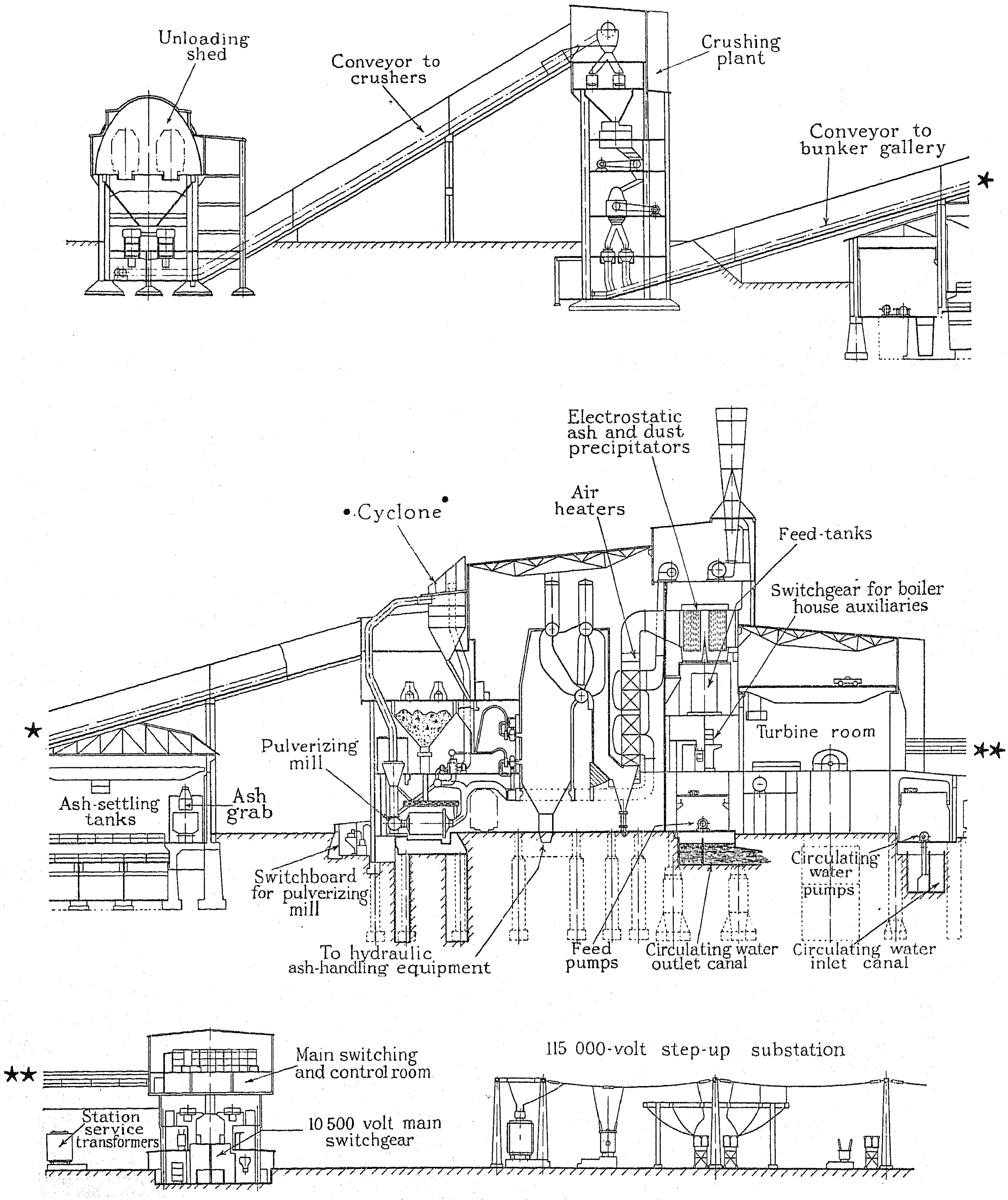

FIG. 11.—Cross-section of power plant at Bobriki.

TABLE 9.

Straight Condensing-Turbine Sets: List of Standard Ratings.

Number	Nominal output of turbo-alternators	Steam conditions at turbine stop-valve: Pressure, atmospheres (absolute)	Steam conditions at turbine stop-valve: Temperature	Speed	Number of bleeding points	Feed temperature under maximum continuous rating conditions
	kVA		° C.	r.p.m.		° C.
1	750	20	350	5 000 / 1 000	—	—
2	1 500	20	350	—	1	65
3	2 500	20	350	—	1	70
4	4 000	29	400	—	1	70
5	6 000	29	400	3 000	2	100
6	12 000	29	400	3 000	3	150–155
7	25 000	29	400	3 000	3	150–155
8	50 000	29	400	1 500 / 3 000	3–4	155
9	100 000	29	400	1 500	3–4	180
10	50 000	55	450	1 500 / 3 000	3–4	180
11	100 000	55	450	1 500	3–4	180
12	200 000	55	450	1 500	4	180

TABLE 10.

Pass-out Turbines for Heating Schemes: List of Standard Ratings.

Number	Nominal output of turbo-alternators	Steam conditions at turbine stop-valve: Pressure, atmospheres (absolute)	Steam conditions at turbine stop-valve: Temperature	Speed	Pass-out pressure (regulated), in atmospheres (absolute)	Quantity of steam passed out, tons per hour: At economical load	Quantity of steam passed out, tons per hour: At maximum load	Type of turbine
	kVA		° C.	r.p.m.				
1	1 500	20	350	5 000 / 1 000	5 ± 0·5	10	6	Combined
2	2 500	20	350	5 000 / 1 000	5 ± 0·5	16	11	Combined
3	4 000	29	400	5 000 / 1 000	5 ± 0·5	25	17	Combined
4	4 000	29	400	5 000 / 1 000	1·2–2	25	15	Combined
5	6 000	29	400	3 000	6 ± 0·5	35	25	Combined
6	6 000	29	400	3 000	1·2–2	35	20	Combined
7	12 000	29	400	3 000	6 ± 0·5	75	45	Standard
8	12 000	29	400	3 000	1·2–2	50	25	Standard
9	25 000	29	400	3 000	6 ± 0·5	150	90	Standard
10	25 000	29	400	3 000	1·2–2	100	40	Standard
11	50 000	29	400	1 500	1·2–2	200	80	Standard
12	50 000	29	400	3 000	1·2–2	200	80	Standard
13	50 000	55	450	1 500	1·2–2	200	80	Standard
14	5 000	55	450	3 000	12–14	100	60	Standard
					1·2–2	130	50	Standard
15	25 000	55	450	3 000	12–14	50	30	Standard
					1·2–2	70	30	Standard

Turbo-Generating Plant.

A start was made with steam turbo-generating plant, and in July, 1929, the first of a series of standard specifications was issued. This specification is now being superseded, and the revised standard sizes of generating units are shown in Table 8. The Soviet authorities fully appreciate that these standards are not in accordance with the standards of the International Electrotechnical Commission, but they feel that the 10 sizes of units named would fulfil all their requirements. Moreover, they wished to avoid setting their young and undeveloped factories the task of manufacturing the 13 standard sizes of units which it would have been necessary for them to adopt had they fallen in line with the recommendations of the International Electrotechnical Commission. In dealing with the question of power factors and terminal voltages for the larger units, the Soviet engineers have taken into consideration the fact that determined endeavours are being made by the various electricity-supply authorities to improve the power factor of their networks; consequently they have specified a power factor of 0·9 in connection with the generators of the larger units. On the other hand they have realized that efforts at power-factor correction will not result in immediate improvement, and therefore they have called for the two types of machines which are to be developed and built as standard in the immediate future, i.e. the 50 000-kW and 100 000-kW 1 500-r.p.m. sets which are capable of developing full output at 0·85 power factor and with terminal voltages of 11 000 volts and 15 750 volts respectively. In order that the generators may meet this specification the rotors are allowed to have a 95 degrees C. temperature-rise with an air temperature of 25° C. Similarly a machine rated at 25 000 kW must be capable of developing this full-load output with a power factor of 0·75 and a terminal voltage of either 11 000 volts or 6 600 volts.

The ratings of steam turbines which it is intended to standardize in the U.S.S.R. are shown in Tables 9 and 10. It will be noticed that up to 6 000 kW the Russians are proposing to utilize combined sets of the type which has been developed in Great Britain in recent years, having a turbine and condenser on a common bedplate and with gearing and a low-speed generator.

Actual performance specifications have not yet been finally drawn up or standardized, but in this connection it may be noted that the standardizing authorities in framing their performance specifications have adopted a standard vacuum of 95 per cent with a cooling-water temperature of 15° C.

Boilers.

From Tables 8 and 9 it will be seen that the steam pressures and temperatures at the turbine stop-valves are to be standardized as follows:

20 atmospheres abs. (280 lb. per sq. in. gauge) at 350° C.
29 atmospheres abs. (412 lb. per sq. in. gauge) at 400° C.
55 atmospheres abs. (800 lb. per sq. in. gauge) at 450° C.

The corresponding standard boiler-room conditions have therefore been adopted as follows:—

Boiler pressure (atmospheres abs.)	23	33	64
,, ,, (lb. per sq. in. gauge)	323	486	942
Steam temperature, ° C.	375	425	470
Feed-water temperature, ° C.	up to 100	155	180
Hot-draught temperature, ° C.	—	up to 400	up to 400

It has also been decided that boiler ratings shall in future be expressed in metric tons of steam evaporated per hour, and not in terms of heating surface. The proposed standard evaporation capacities in metric tons per hour are as follows:—

Nominal	6	12	20	(30)	40	60	90	126	160	225
Maximum continuous ..	7·5	15	25	(37·5)	50	75	110	155	200	280

The recommended sizes of boilers for standard generator units are shown in Table 11.

Transformers and Switchgear.

Transforming plant and switchgear have also had the attention of the standardization authorities, and Fig. 11 has been prepared with a view to indicating briefly the lines upon which the Soviet engineers propose to lay out their larger power stations. This diagram relates to the standard type of station having an initial capacity of 150 000 kW and capable of extension to 250 000 kW. Five such stations are under construction at the present time. It will be noticed that where three generators only are installed they are direct-connected to three-winding transformers for feeding 35 000-volt and 110 000-volt networks; but in the event of these stations being called upon to supply the bulk of their output to the 110-kV network, only two, or possibly three, of the generators would be connected to three-winding transformers and the remaining two sets would supply the whole of their output (with the exception of the supply to the auxiliaries) to the 110-kV network.

Transformers.

Standards are being prepared for transforming plant; Tables 12 and 13 indicate the ratings which the Soviet

TABLE 11.

Output	Maximum steam consumption of straight condensing turbo sets at maximum continuous load	Maximum steam consumption of pass-out turbo sets at maximum continuous load and with maximum quantity of steam passed out	Nominal boiler capacity	Number and capacity of boilers
kW	tons per hour	tons per hour	tons per hour	
750	4·5	—	6	1 boiler or more, according to local conditions
1 500	8·5	—	6 or 12	Depends on local conditions
2 500	13·5	—	12	1 boiler
4 000	20·4	—	20	1 boiler
6 000	29·4	—	20 or 40	Depends on local conditions
12 000	60·0	—	60	1 boiler
1 500	—	14·5	12	1 boiler for each turbine, with spare boilers
2 500	—	24·0	20	1 boiler
4 000	—	33·57 40·70	20 or 40	Depends on local conditions
6 000	—	45·8 59·5	40 60	1 boiler 1 boiler
12 000	—	90	90 or 60	1 boiler of 90 tons per hour for each turbine, or 3 boilers of 60 tons per hour for 2 turbines
25 000	112·5	—	120	1 boiler of 120 tons per hour
25 000	—	162	160 or 120	1 boiler of 160 tons per hour to each turbine, or 3 boilers of 120 tons per hour for 2 turbines
25 000	—	220	225 or 160	1 boiler of 225 tons per hour to each turbine, or 3 boilers of 160 tons per hour for 2 turbines
50 000	225·5	—	225 or 160	1 boiler of 225 tons per hour to each turbine, or 3 boilers of 160 tons per hour for 2 turbines
50 000	—	305–315·0	160 or 225	1 boiler of 160 tons per hour to each turbine, or 3 boilers of 225 tons per hour for 2 turbines
100 000	441–450	—	225	2 boilers of 225 tons per hour

TABLE 12.

Standard Ratings and No-Load Transformation Ratios for Step-up Transformers.

Three-phase

Nominal rating, kVA	Nominal voltage of l.t. windings, kV			Nominal voltage of h.t. windings, kV		
3 200	6·3	10·5	38·5	—	—	—
4 200	6·3	10·5	38·5	—	—	—
5 600	6·3	10·5	38·5	—	—	—
7 500	6·3	10·5	38·5	121	—	—
10 000	6·3	10·5	38·5	121	169	—
15 000	6·3	10·5	38·5	121	169	242
20 000	6·3	10·5	38·5	121	169	242
31 500	6·3	10·5	38·5	121	169	242

Single-phase

Nominal rating, kVA	Nominal voltage of l.t. windings, kV				Nominal voltage of h.t. windings, kV		
2 500	6·3	10·5	—	38·5	121	—	—
3 333	6·3	10·5	—	38·5	121	—	—
5 000	6·3	10·5	—	38·5	121	169	—
6 667	6·3	10·5	—	38·5	121	169	—
10 500	6·3	10·5	—	38·5	121	169	242
13 500	6·3	10·5	—	38·5	121	169	242
20 000	—	10·5	—	38·5	121	169	242
37 500	—	—	15	38·5	121	169	242

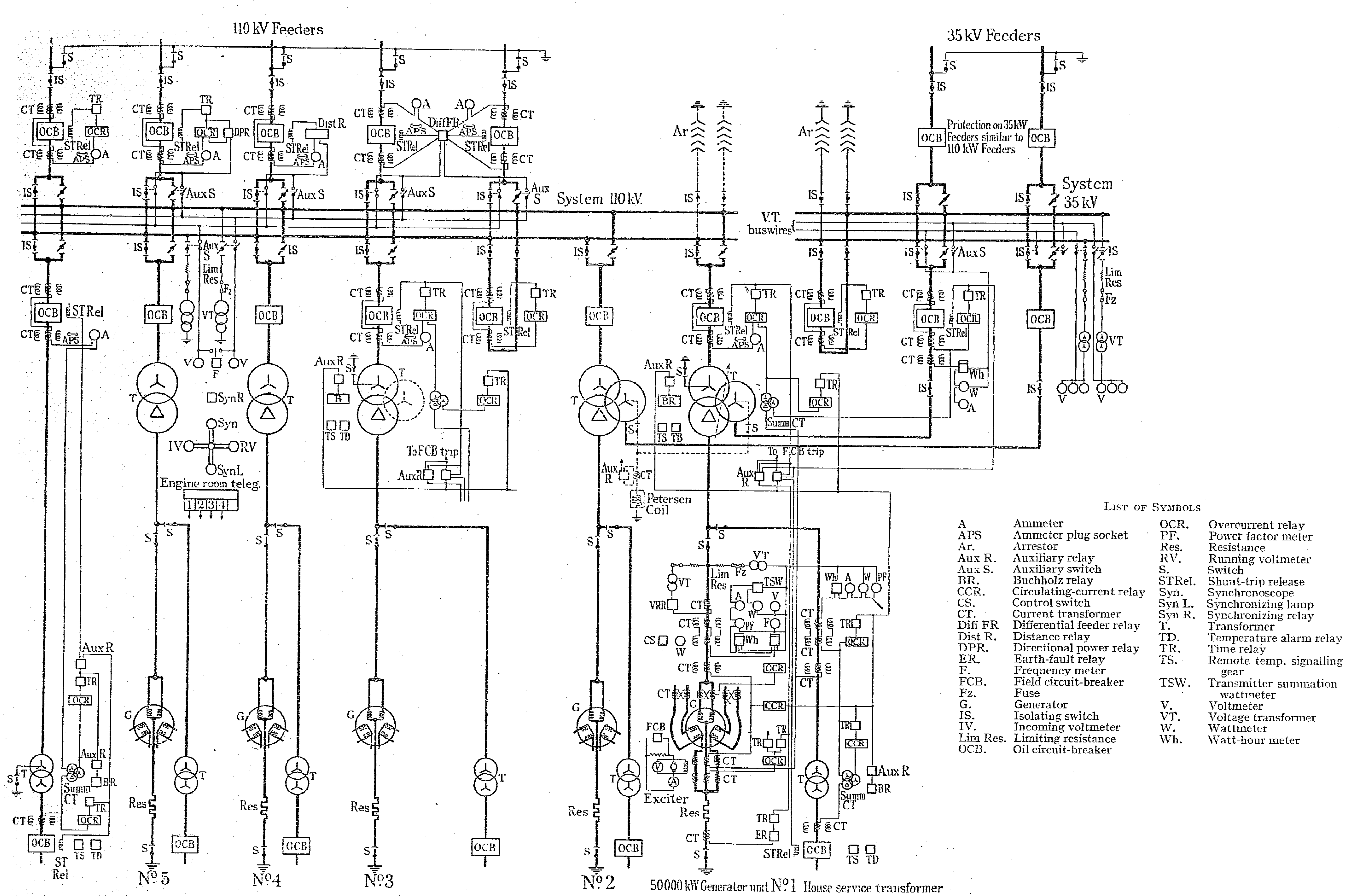

Fig. 12.—Diagram of connections for typical generating station proposed as standard in the U.S.S.R.

TABLE 13.

Standard Ratings and No-Load Transformation Ratios for Step-down Transformers.

Nominal rating, kVA	Nominal voltage of h.t. windings, kV							Nominal voltage of l.t. windings, kV				
Three-phase												
3 200	—	—	—	—	110	—	—	3·3	6·6	11	38·5	—
4 200	—	—	—	—	110	—	—	3·3	6·6	11	38·5	—
5 600	—	—	—	—	110	—	—	3·3	6·6	11	38·5	—
7 500	6·3	10·5	15	35	110	—	—	3·3	6·6	11	38·5	—
10 000	6·3	10·5	15	35	110	154	—	3·3	6·6	11	38·5	—
15 000	—	10·5	15	35	110	154	220	3·3	6·6	11	38·5	—
20 000	—	—	—	35	100	154	220	—	6·6	11	38·5	—
31 500	—	—	—	35	100	154	220	—	6·6	11	38·5	121
Single-phase												
2 500	6·3	10·5	15	35	110	—	—	3·3	6·6	11	38·5	—
3 333	6·3	10·5	15	35	110	—	—	3·3	6·6	11	38·5	—
5 000	—	10·5	15	35	110	154	—	3·3	6·6	11	38·5	—
6 667	—	—	—	35	110	154	—	—	6·6	11	38·5	—
10 500	—	—	—	35	110	154	220	—	6·6	11	38·5	—
13 500	—	—	—	—	110	154	220	—	6·6	11	38·5	121
20 000	—	—	—	—	110	154	220	—	—	11	38·5	121
37 500	—	—	—	—	110	154	220	—	—	11	38·5	121

engineers will in all probability standardize for two-winding step-up and step-down transformers. In these tables the nominal h.t. voltage ratings are understood to imply the voltage between phases of the line when the h.t. windings of the transformers are star-connected.

The h.t. windings of both step-up and step-down transformers are to be provided with four additional tappings as follows: — 4·5 per cent, — 2 per cent (nominal), + 2 per cent, + 4·5 per cent. The actual voltages specified for the various tappings for the h.t. windings of different transformer voltages is shown in Table 13.

It is realized that in special circumstances special tappings may be necessary.

The impedance voltages of both step-up and step-down transformers have been specified as follows:—

Nominal voltage of h.t. winding	Impedance voltage as percentage of h.t. voltage
kV	per cent
6·3	10
10·5	10
15	10
35 and 38·5	7·5 or 8
110 and 121	10
154 and 169	11
220 and 242	12

TABLE 14.

Standard Tapping Voltages for Transformers.

Tapping Number	Voltages						
Step-up Transformers							
	kV	kV	kV	kV			
1	40·4	127·05	177·45	254·1			
2	39·45	124·025	173·225	248·05			
3 (Nominal voltage)	38·5	121·0	169·0	242·0			
4	37·55	117·975	164·775	235·95			
5	36·6	114·95	160·55	229·9			
Step-down Transformers							
	kV	kV	kV	kV	kV	kV	kV
1	6·6	11·0	15·75	36·75	115·0	161·7	231·0
2	—	10·75	15·375	35·875	112·5	157·85	225·5
3 (Nominal voltage)	6·3	10·5	15·0	35·0	110·0	154·0	220·0
4	—	10·25	14·625	34·125	107·5	150·15	214·5
5	6·0	10·0	14·25	33·25	105·0	146·3	209·0

The high value of the impedance voltage for transformers having a nominal h.t. voltage of 15 000 volts and under has been chosen because transformers of this voltage are quite frequently employed for supplying station requirements and are then connected directly to the station busbars or to the terminals of the generators.

In dealing with three-winding transformers and transformer groups, the proposed standards are generally in agreement with those outlined for two-winding transformers. The nominal rating of the transformer is that of its highest-ratio winding. The following ratios of loading for the three-winding transformers have been put forward as standard:—

Number 1 winding	Number 2 winding	Number 3 winding
100	100	100
100	100	66·7
100	66·7	100
100	66·7	66·7

In a country where climatic conditions vary as greatly as they do in most parts of Russia, the question of transformer cooling raises many difficulties. The summer outdoor shade temperature in many of the industrial districts of the U.S.S.R. reaches 55° C., and winter temperatures as low as −45° C. (and in some cases −50° C.) occur.

The majority of the earlier stations built under the G.O.E.L.R.O. plan adopted systems wherein the oil from the transformer groups was circulated through special water-cooled coolers. This system has in general been adopted at step-up substations in the vicinity of the large power stations, where a suitable power supply for working the pumps, etc., and supervision are available; but more recently a large number of naturally-cooled transformers with radiator-type cooling-systems have been installed.

Switchgear.

No serious attempt has yet been made to adopt standards in relation to switching plant, but two groups of Soviet engineers are investigating questions relating to short-circuit conditions in large networks and to the necessary rupturing capacity of switches. For the purpose of gaining information for these investigations a very complete laboratory has recently been equipped in Moscow, with a short-circuit-calculating table from which the conditions obtaining in any part of the Russian network can be ascertained, and also with a complete short-circuit oil-switch testing-equipment, including a specially designed 50 000-kW testing-generator.

Transmission Lines.

The distribution voltages now in general use in the U.S.S.R. are 6·3, 10·5, and 15 kV, for local distribution, and for long-distance transmission lines 35, 110, 154, and 220 kV. These are the average voltages at the customers' end of the line. The line linking the new Svir hydro-electric station with Leningrad is the first 220-kV line to go into commercial operation in the U.S.S.R.

In the majority of earlier transmission lines copper conductors were employed, but more recently a number of lines have been put up using steel-cored aluminium

Table 15.

Proposed Standard Transmission-Line Conductors and Spans.

Voltage	Material	Cross-sectional area	Maximum span	Maximum sag	Maximum permissible stress in conductor	Critical span
kV		mm²	m	m	kg/mm²	m
35	Steel-aluminium	35	170	5·57	9·9	80
35	Copper	35	170	5·43	19·0	79·8
35	Steel-aluminium	50	190	5·64	9·9	117
35	Copper	50	190	5·43	19·0	101·4
35	Steel-aluminium	70	200	5·36	9·9	143
35	Copper	70	200	5·29	19·0	124
35	Steel-aluminium	95	215	5·40	9·9	172
35	Copper	95	215	5·41	19·0	149
35	Steel-aluminium	120	225	5·40	9·9	188
35	Copper	120	225	5·51	19·0	169
110	Steel-aluminium	35	170	5·57	9·9	80
110	Steel-aluminium	50	190	5·64	19·0	117
110	Steel-aluminium	70	200	5·36	9·9	143
110	Copper	70	200	5·29	19·0	124
110	Steel-aluminium	95	215	5·40	9·9	172
110	Copper	95	215	5·41	19·0	149
110	Steel-aluminium	120	225	5·41	9·9	188
110	Copper	120	225	5·51	19·0	169

conductors. The standards for the mechanical stresses permissible in the conductors and for the design of poles have had the close attention of the Soviet standardization authorities, particularly in view of the extremely bad ice conditions which are frequently encountered. The standard specification shortly to be issued will call for all transmission lines to be designed to withstand the stresses set up by a 20-metre-per-sec. wind blowing when the conductors are coated with a covering of ice 10 mm in thickness. Table 15 gives some particulars of the sizes of conductors which are to be standardized, and also of standard spans.

The type of tower employed on 110 000-volt lines in general, and on the 154 000-volt lines radiating from Dnieprostroi, is one of relatively light lattice construction but with a considerably larger base area than the towers in use on the British grid. Questions of way-leaves and space occupied by the bases of the towers are of relatively minor importance in the U.S.S.R. The 115-kV line connecting the Volhov hydro-electric station with Leningrad (75 miles) has been built with wooden poles which have been in satisfactory operation for the last 9 years. The majority of the 35 000-volt lines throughout the country have also been run on wooden poles, and a very considerable amount of attention has been given to the standardization of design of wooden-pole lines of this type. Figs. 13 and 14, in conjunction with Table 16, indicate the standard types of wooden intermediate and anchor poles which are being adopted.

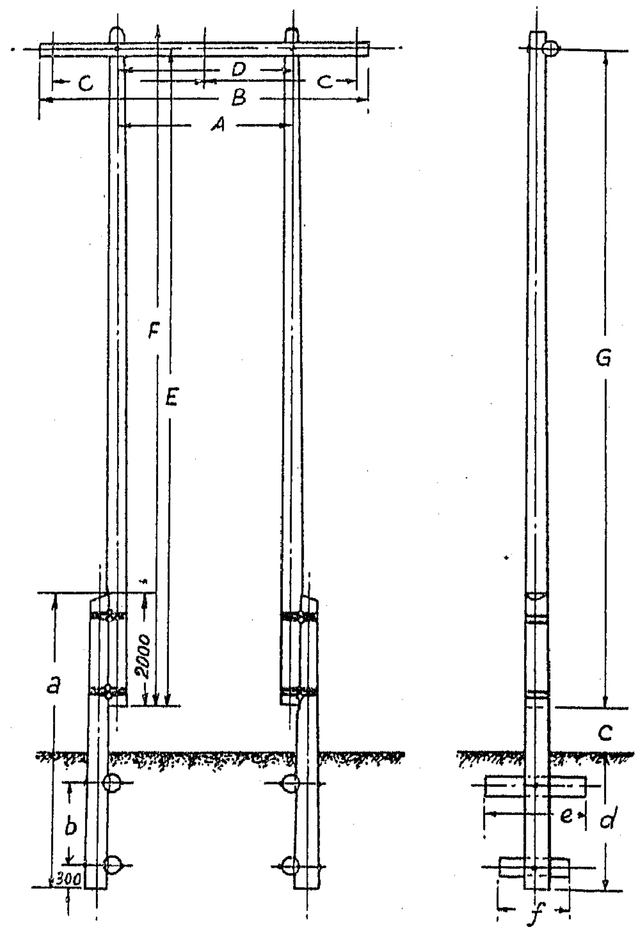

FIG. 13.—Standard wooden intermediate pole.

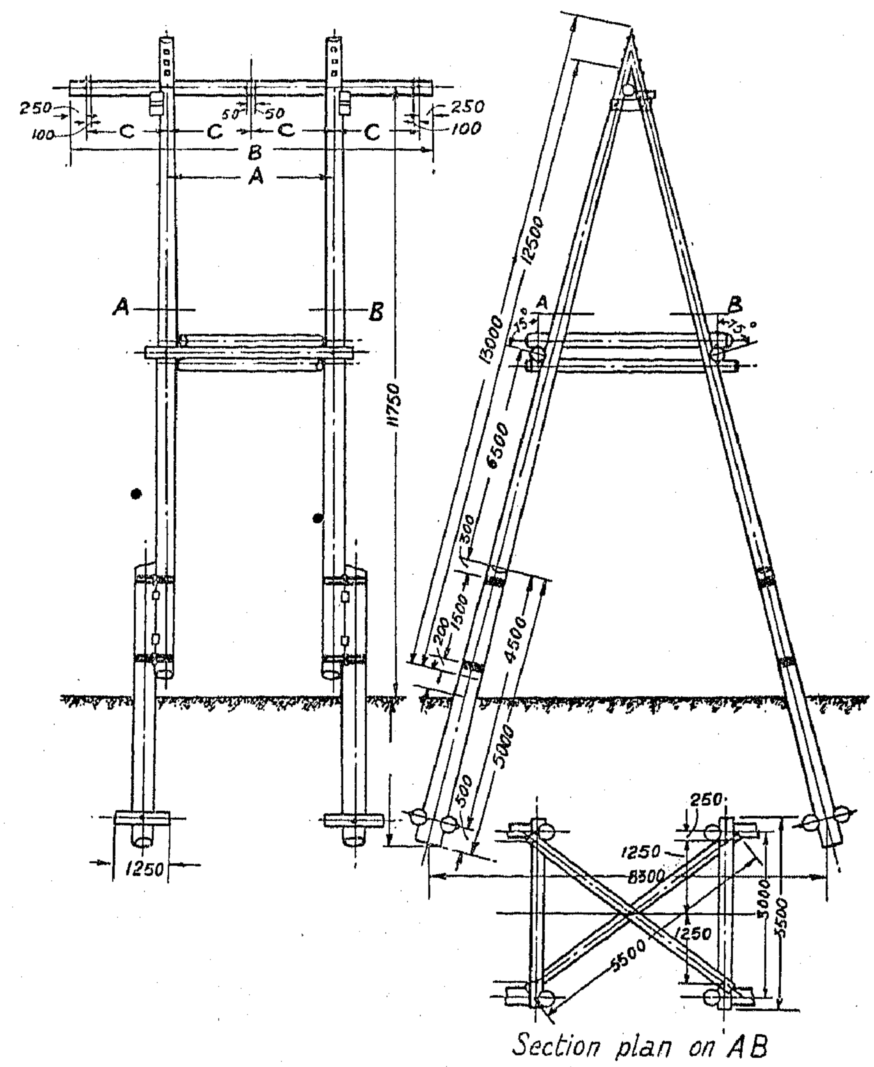

FIG. 14.—Standard wooden anchor pole.

CABLES.

Standards for power and distribution cables were amongst the first worked out by the Soviet standardization authorities. These standards are now under revision. A new specification covering paper-insulated cables for voltages up to 35 kV has recently come into force (28th November, 1933). This document is probably one of the most complete cable specifications which has ever been issued by any standardizing authority. It deals in detail with the permissible current-loading on cables laid under different surrounding conditions, and it lays particular stress on questions of loss measurement, pointing out that this criterion is of much greater importance to the life of the cable than insulation-resistance measurements taken in the usual manner.

The standards commission have also emphasized the necessity of specifications not being confined to showing maximum conditions of service but also indicating optimum working conditions.

In issuing this specification the authorities have indicated the desirability of standards being worked out for cable-impregnating compounds.

PROTECTIVE GEAR.

Considerable difference of opinion still exists amongst the Soviet engineers as to the most satisfactory types of protective gear, but, generally speaking, the tendency would appear to be to use distance (impedance) protection on long-distance h.t. transmission lines. On local networks having distances not in excess of 12 km the Translay system of protection has been very generally adopted, and this system will probably be

made standard. Both in Leningrad and in Moscow a special form of split-conductor protection, in which the main conductor is paralleled by an insulated core of 1/20th its cross-section, has been used for protecting the secondary 35 000-volt distribution system, with entirely satisfactory results, but it is apparently not intended that this system should be put into general use as a standard system of protection, owing to the excessive cost of the special cables required.

For generator protection the earlier stations were provided with overload relays and a straight Merz-Price circulating-current protection in which the neutral point is solidly earthed. This arrangement has, however, been superseded by the scheme shown in Fig. 12. Merz-Price protection has also been used generally for transformer protection, but in the most recent stations the arrangement shown in Fig. 12 is being adopted. Buchholz relays are also being generally applied.

Russian engineers as a whole tend to overstress the mathematical and theoretical side of engineering, and therefore it is not surprising that a very great deal of attention has been paid by them during recent years to problems associated with short-circuit conditions and protective systems generally.

SUPERVISORY CONTROL AND DISPATCHER SYSTEMS.

In each of the larger industrial areas—for instance, Moscow, Leningrad, Donetz Basin, etc.—supervisory control and dispatcher systems have been put into operation. Although the apparatus installed has given satisfaction, these systems have not yet been used to the fullest advantage, owing largely to the inexperience of the operating staff and the excessive caution which fear of being responsible for an error of judgment produces amongst operating engineers in the U.S.S.R. to-day. This remark is one that is not entirely confined to technical men in the "dispatcher" services but to operating and constructional engineers in general.

TABLE 16.

Table of Main Dimensions of Standard Wooden Transmission-line Poles.

	35 kV			110 kV		
	Cross-sectional area of conductor, mm^2			Cross-sectional area of conductor, mm^2		
	35	50 and 70	95 and 120	35	50 and 70	95 and 120
Diameters of timbers used:	mm	mm	mm	mm	mm	mm
(*a*) For poles	210	230	240	210	213	240
(*b*) For pole footings ..	290	320	330	300	330	340
(*c*) For cross-arm	180	180	180	200	200	220
		Intermediate Poles				
Dimensions on drawings.	m	m	m	m	m	m
A	3·000	3·000	3·000	4·000	4·000	4·000
B	6·500	6·500	6·500	8·500	8·500	8·500
C	3·000	3·000	3·000	4·000	4·000	4·000
D	1·500	1·500	1·500	2·000	2·000	2·000
E	10·650	10·650	10·650	12·650	12·650	12·650
F	11·000	11·000	11·000	13·000	13·000	13·000
G	12·700	12·750	12·650	13·200	13·250	13·150
a	6·500	6·500	6·500	5·000	5·000	5·000
b	—	1·600	1·700	—	1·600	1·700
c	2·050	2·100	2·000	550	600	500
d	2·450	2·400	2·500	2·450	2·400	2·500
e	—	1·500	1·500	—	1·500	1·500
f	—	1·000	1·000	—	1·000	1·000
		Anchor Poles				
A	3·000	3·000	3·000	4·000	4·000	4·000
B	6·500	6·500	6·500	8·500	8·500	8·500
C	1·500	1·500	1·500	2·000	2·000	2·000

ELECTRICAL MANUFACTURE IN THE U.S.S.R.

A short survey of this description will hardly permit of proper justice being done to the great efforts which the Soviet authorities have made during recent years to organize their electrical manufacturing industries. The whole of the country's electrical and power-plant manufacturing facilities have been grouped into trusts under the Commissariat of Heavy Industries. The actual grouping of the various works has recently been under revision, but the total number of employees in the

electrical manufacturing industry at the present time amounts to approximately 115 000 persons. Some idea of the scope of the various works which are already in operation can be gathered from the particulars given in Table 17. These works have prepared for themselves most ambitious production programmes, which in most cases they have not been able to keep owing primarily to inexperience and lack of co-ordination with suppliers of raw materials. On the whole, however, the strides which have been made have been surprisingly satisfactory. The Electrosila Works in Leningrad may be quoted as an instance of what is being done. This works has recently turned out seven 50 000-kW turbo-generators and has completed four of the 77 500-kVA low-speed generators for Dnieperstroi. The whole of the generating plant for the Svir hydro-electric station is being built in this factory. The Electro-Mechanical Works in Harkov has recently built a number of 10 000-kW motor-generator sets for the aluminium plant at Zaporoji. The new Electric Traction Works at Kashira is still under construction, but the Dynamo Works at Moscow has recently completed a number of 3 000-volt, 2 725-h.p., 130-ton locomotives. Table 18 gives some details of the growth of certain of the State electrical manufacturing enterprises in the U.S.S.R. during recent years. The lamp department of Electrozavod in Moscow produced 42 million lamps in 1932. Its automobile equipment department is manufacturing per day 500 car sets of electrical equipment, including self-starters, magnetos, etc.

TABLE 17.

MAIN ELECTRICAL MANUFACTURING ENTERPRISES OF THE COMMISSARIAT OF HEAVY INDUSTRIES.

LENINGRAD DISTRICT.

(1) *Stalin Metal Works.* An old-established works, which has been brought thoroughly up to date during the last 10 years, manufacturing steam boilers of all standard capacities up to 225 tons per hour, condensing plant, steam turbines up to 50 000 kW capacity, and hydraulic turbines of all sizes.

(2) *Electrosila Works* (previously Siemens Schuckert Works). This works has been greatly enlarged and manufactures large generating plant, including turbo-alternators up to 50 000 kW capacity and the heaviest types of motor power generators, rolling-mill motors, etc. It has a separate department for the mass production of small motors and also for mercury-arc rectifiers and marine equipment.

(3) *Electrik.* This specializes on the manufacture of electric welding equipment and induction furnaces.

(4) *Electroapparat.* A switchgear factory making every kind of heavy switchgear.

(5) *Electropribor.* Switchboard indicating and measuring instruments of all kinds, house service meters, etc. This works has a special section for the manufacture of Sperry gyroscopes.

(6) *Radio Works.* Radio equipment of all kinds and X-ray apparatus.

(7) *Svetlana Works.* A large new factory devoted to the manufacture of radio transmitting valves, rectifiers, and radio receiving valves.

(8) *Krasni Zoria Telephone Works* (previously the Ericsson Works). This factory has been greatly extended and now manufactures every kind of telephone equipment, including complete automatic exchanges.

(9) *Northern Cable Works.* Cables and wires of all kinds.

(10) *Proletari Porcelain Works* (previously the Royal Porcelain Factory). This now has an extensive electrical porcelain department.

(11) *Electrosvet.* This makes lamps and fittings.

MOSCOW DISTRICT.

Electro-Combinat (*Electrozavod*). A large factory established during the early years of the Five Year Plan and now divided into three sections:—

(12) (*A*) *A.T.E. Works*, devoted to the manufacture of electrical equipment for automobiles and tractors.

(13) (*B*) *Transformer Works*, making all sizes of transformers. This works recently completed the 20 000-kV single-phase transformers which will go to constitute the 60 000-kVA main step-up groups for the Svir–Leningrad 220-volt transmission line.

(14) (*C*) *Lamp Works.* This works produced 42 million lamps in 1932. It makes 35 types of lamps and has special sections for neon-tube advertising signs, sodium lamps, etc.

The Electro-Combinat also has a department for manufacturing electric arc furnaces. In 1933 a 3 500-kW 12-ton furnace built by this works was put into satisfactory operation.

(15) *Dynamo Works* (previously the Russian Dynamo Co.). An associate of the Westinghouse Companies of Great Britain and America. This works has been greatly extended and now employs over 12 000 hands, manufacturing traction equipment of all kinds, electric locomotives, crane equipments, accumulator trucks, etc.

(16) *Moscow Telephone Works.*—Telephones and telegraphic equipment.

(17) *Projector and Domestic Equipment Works.* In course of construction.

(18) *Kashira Locomotive Works.* In course of construction.

(19) *Isolator Works.* Electrical porcelain of all kinds and high-tension bushings.

(20) *Isolite Works.* Electrical insulating materials.

(21) *Moscow Cable Works.* This works was originally established in 1911 to manufacture power and telephone cables under licence from the British Insulated and Helsby Cable Co. It has now been greatly increased in size and produces all kinds of cables and insulated wires.

(22) *Moscow Röntgen Works.* X-ray equipment.

(23) *Electrougli.* Carbons for brushes, accumulators, etc.

(24) *Mercury-Arc Rectifier Works.* In course of construction.

(25) *Electric Lamp Works.* Work was started in 1933 in the building of a very large electric lamp and valve works, which will have its own feeder works, including glass works and Wolfram filament works. This works will have an output of 100 million lamps per year.

TAMBOG DISTRICT.

(26) *Revtrud Works.* This works makes smaller types of electrical equipment and has recently been entrusted with the manufacture of steam-turbine-driven train-lighting sets in three sizes: 0·5 kW for locomotive head-lamps, and 5 kW and 7·5 kW for train lighting.

HARKOV DISTRICT.

(27) *Harkov Electromechanical Works.* This factory was originally built in 1915–1917 by the Russian General Electric Co.—an associate of the A.E.G. and the G.E. Co. of America. It has been greatly extended during recent years and now produces large motor-generators, industrial motors, industrial switchgear and control gear, relays, meters, etc. The large new steam turbine and large generator factory now being built alongside the Harkov Electromechanical Works by Turbostroi will ultimately become part of the works. This plant is designed to manufacture 2 000 000 kW of steam-power generating-plant per annum.

JAROSLAVL DISTRICT.

(28) *Electrical Machine Building Works.* This works which specializes in building industrial motors was erected in 1926–1928 by the A.S.E.A. of Sweden under concession, but has now been transferred to the All Union Electrical Trust.

URAL MOUNTAIN DISTRICT.

(29) *Volta Works.* This is a relatively small works evacuated from Talinin (Revel) in 1916. It makes motors and industrial equipment.

(30) *Ural Electrical Machine Building Combine.* This large works is now under construction. As designed it will ultimately be one of the largest electrical works in Europe and will make all kinds of electrical equipment.

The steam-turbine manufacturing departments of the Leningrad Metal Works had calculated to complete over 1 million kW in steam turbines during 1932, but this figure was not reached, owing primarily to difficulties with raw materials.

One of the greatest tasks in their programme has been the extension of the Harkov Electromechanical Works, where a turbine and turbo-generator manufacturing plant has been laid down designed to produce 2 million kW of steam-turbine plant per annum. This vast concern, however, will not be the largest electrical manufacturing works in the U.S.S.R., since the foundations have now been laid for a large electrical manufacturing centre at North Sverdlovsk in the Eastern Urals. This centre, which will constitute a town in itself, will make every kind of electrical equipment and, when completed, will employ some 60 000 operatives, for whom housing accommodation and welfare facilities are also being built.

The figures given above are probably sufficient to indicate that the Soviet authorities are rapidly building up for themselves an electrical manufacturing industry capable of supplying their own requirements.

Railway Electrification.

The plans of the G.O.E.L.R.O. not only foresaw the extensive use of electrical power in industry, but also provided for the electrification of many of the country's main-line railways. The Soviet intends to electrify

Table 18.

Production of State Electrical Manufacturing Enterprises in U.S.S.R., 1924–32.

	Turbo-generators		Transformers		Oil switches of all kinds	Motors over 100 kW, total capacity	Electric welding sets, total capacity
	Number	Total capacity	Number	Total capacity			
		1 000 kW		1 000 kVA		kW	kW
1924/5	7	10·3	1 468	199·4	—	—	—
1925/6	5	7·5	1 798	260·0	611	—	—
1926/7	20	53·4	2 157	317·0	3 427	31 670	578
1927/8	26	75·4	3 024	403·2	1 812	64 723	278
1928/9	35	137·3	4 303	491·1	4 506	48 264	728
1929/30	57	186·0	7 551	1 525·3	7 222	88 318	16 755
1st Oct.–31st Dec., 1930	18	66·7	2 943	563·6	2 609	20 949	6 230
Total 1930	65	215·3	9 262	1 807·7	8 359	91 282	20 480
1931	67	518	13 740	3 182·4	13 076	109 400	84 923
1932	—	—	8 283	3 572·0	11 592	325 254	—

(Note.—This Table only covers certain major products and does not represent the output of the whole electrical industry in the U.S.S.R.)

some 3 800 km of railway line before 1937. The ultimate railway electrification plan of the Soviet Government is shown in Fig. 15. For suburban electrification, 1 500-volt direct current is being used, with overhead contact lines and mercury-arc rectifiers in the sub-

The question of what voltage and what system will ultimately be adopted for long-distance main-line electrification has not yet been finally settled. One of the less-important lines running into Moscow is being equipped for trying out various extra-high-tension single-

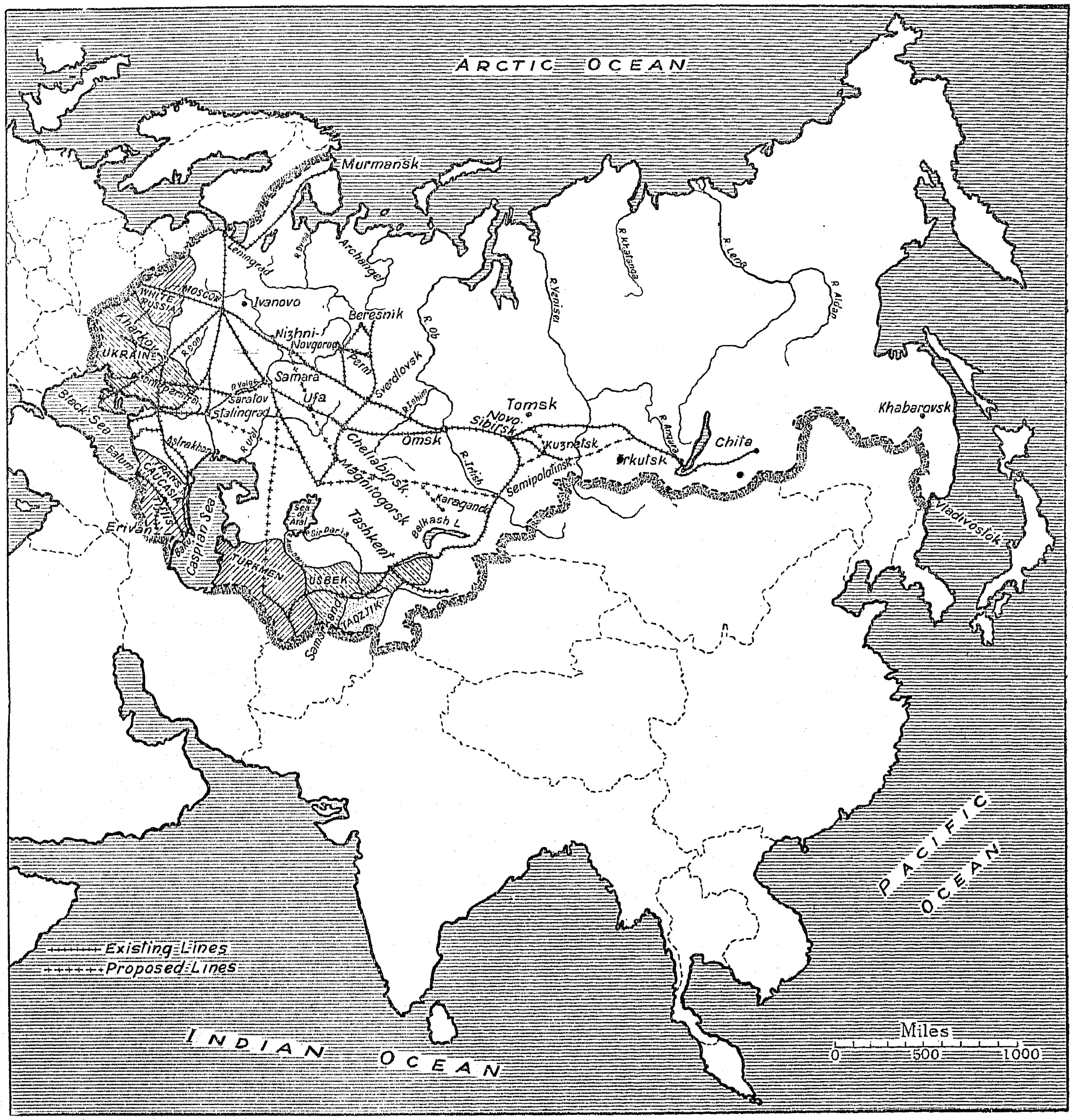

Fig. 15.—Proposed railway electrification developments in the U.S.S.R., showing lines which it is intended to electrify.

stations. On certain of the mountain divisions in the Caucasus and the Urals, where electrification has been resorted to primarily to solve braking difficulties, 3 000-volt direct current has been adopted, fed to the locomotives by overhead contact wires, and using motor-generator sets in the substations.

phase and direct-current systems, in order that information may be obtained to assist in settling the controversy which is going on amongst Russian engineers on this question.

This experimental line is being built for 20 000 volts, 50 cycles, single-phase, on the overhead-contact wire,

and it is intended to collect experimental data on locomotives equipped with (*a*) single-phase 50-cycle motors, (*b*) the Kando system, (*c*) the Punga-Schön system, (*d*) the Westinghouse split-phase system; and also with a locomotive designed to work with 20 000-volt direct current on the contact wire and equipped with inverted rectifiers supplying 3-phase motors.

The electrification of the main Trans-Siberian line is also held in view, but this task presents many difficult transmission problems, particularly in connection with that part of the line between the Ural Mountains and Novo-Sibirsk. On this section of the line the Soviet engineers would like to be in a position to transmit power over distances of more than 500 miles to traction substations. Experimental institutions in Leningrad have been entrusted with the task of reporting as to what form of transmission, if any, might be adopted in this particular case. Although work is proceeding on the development of super-tension 50-cycle a.c. transmission, the possibilities are being considered of a high-tension direct-current system using grid-controlled high-tension rectifiers, and also of a half-wave transmission system.

Research.

No review of electrical developments in the U.S.S.R. could be considered complete without some reference being made to the extreme importance which the Soviet authorities attach to research and experimental work. In the foregoing résumé of developments in the burning of peat fuel and in the solving of transmission and other problems, it will have been seen that Soviet engineers are engaged on extensive experimental work in the field. On the other hand, academic and fundamental research work is having the closest attention, and very large electrical research laboratories have been developed in various parts of the Union. The work of these laboratories is controlled by the Central Research Council of the Commissariat of Heavy Industries.

As an example of the size and scope of these laboratories, the All Union Electrotechnical Institute in Moscow may be cited. This is the central fundamental research institution to which the various works and factories of the All Union Electrotechnical Trust—V.E.T.—send their more complicated problems and those investigations which they feel are beyond the scope of their individual, although quite extensive, research departments. The V.E.I. Laboratories employ over 1 700 workers, some 800 of whom are men with university training. The departmental chiefs are, almost without exception, men who occupy professorial chairs in the universities.

Electrical research laboratories of no less size and importance than the V.E.I. also exist in Leningrad; but for the most part the Leningrad laboratories confine their attention to problems dealing with the lighter side of electrical engineering and to extra-high-tension work. Large central research centres are also being built in Harkov (Ukraine), Sverdlovsk (Urals), Tomsk (Central Siberia), and Tashkent (Central Asia). The organization at Tashkent is making a special study of means of utilizing solar heat in connection with the development of the arid desert areas of Turkestan and Kazakstan.

In the Crimea a small electric power station (140 kW) utilizing wind power has been completed.

Conclusion.

From the foregoing summary of electric developments in the U.S.S.R. during the last 10 years, it will be seen that the plans of the G.O.E.L.R.O. authorities and (more latterly) Gosplan have been attended with considerable success. There is little doubt that in this particular industry more has been achieved than in many other branches of the country's economic life.

Discussion before The Institution, 10th January, 1935.

Mr. T. G. N. Haldane: The author's experience of Russia extends over practically the whole period from 1911 to 1933, and during those 22 years he took part in every important event in that country, and worked in every part of it. It would be interesting if he would tell us the total of kilowatts of plant which he himself has installed. The paper is not only an exceedingly authoritative statement of what has happened in Russia but it also gives a very clear picture of the development which has yet to take place. I think, too, that we can appreciate after reading this paper why it is that the U.S.S.R. is so rapidly approaching a leading position amongst the industrial countries of the world. That, as the author has pointed out, is clearly shown by Fig. 1, which gives the rate of growth of electrical consumption in Russia over the last 10 years or so.

During my brief visit to Russia in 1932 I took a few photographs which I propose to exhibit now as lantern slides. The first shows the Krasni-October power station on the River Neva just outside Leningrad, one of the peat-burning stations described by the author. When I went over it I was very much impressed by the control-room equipment. There are two very fine control rooms, one for the boiler plant and the other for the switchgear. The total installed capacity is about 110 000 kW, of which two 45 000-kW sets were installed by the author. I remember noticing that live steam was blown into the mass of burning peat as it came down on to the grate, and I should like to ask the reason for this. My next lantern slide shows the Moges power station, Moscow. It is largely a peak-load station and, judging by the paper, it has been heavily overloaded on several occasions, owing to the general shortage of plant which prevailed until recently in the Moscow area. It is connected to all the big base-load stations outside the city. The next lantern slide shows the country in the neighbourhood of the Shatura power station, through which the 110 000-volt lines run from Shatura to Moscow and other parts of the Moscow system. There is a total of about 1 000 000 kW of peat plant already installed in the U.S.S.R., with much more to be installed in the future. The problems of peat burning have to a large extent been solved. A further lantern slide shows the Dnieprostroi dam and power station. The water falls

about 100 ft. over the dam. Step-up transformers are used to raise the voltage from 14 000 to 161 000 volts for transmission to the neighbouring industrial towns, and ultimately to the Donbass coalfields. The river is of gigantic proportions, and it flows extremely fast at this point. The site of the hydro-electro works was formerly a series of rapids; I think there were nine of them, and they made the river impossible for shipping. The object of the whole scheme is twofold: firstly, the production of power; and secondly, to make the river navigable for shipping from the Black Sea up to Kiev, a distance of about 1 000 miles. That may be one of the reasons why the building of the dam took place in advance of the construction of the factories which were to take the load. When I visited the power station the load was only about 20 000 or 30 000 kW, and of course it might have been very much more. No doubt it was considered worth while to finish the dam merely in order to make the river navigable. The next lantern slide shows a small station at Kiev, equipped with an 11 000-kW Russian-built turbine. Much larger turbines are, of course, now being built.

I left the U.S.S.R. with a strong impression regarding the general industrialization of the country; and it was this, that the major difficulty would be the training of the personnel for the power stations and factories. The Russians were, however, taking extremely active steps in this direction. Nearly all the factories, and, I think, some of the power stations, had schools attached to them. The lack of practical ability, in which we are so rich in this country, and the lack of a sense of time, represent two of the big difficulties. I believe Russia will overcome them, but it may take some appreciable time. I also came away very strongly impressed with Russia's immense fuel, water-power, mineral, and food-production resources.

With regard to the thermal-electric stations, I had not realized to how great an extent Russia was using her power stations not only for the production of power but also for the production of heat for domestic purposes. The figures given in the paper show that 850 000 kW of plant used partly for power and partly for heating has already been installed, and a very large amount is awaiting installation. I found the Russians critical of British practice; they said "The efficiency of your power stations is so low—you get only 25 per cent. We aim at getting more like 70 or 80 per cent, by making use of the waste heat." There is something in that criticism. Even allowing for the climatic differences between the two countries, it is a little difficult to understand why there has been so little development in this country of the thermal station where the waste steam or condensing water is used for heating purposes.

Fig. 2 illustrates one of the electrical problems with which Russia is faced, namely, the transmission of enormous blocks of power over enormous distances. Even in 1932 Russian engineers were talking quite cheerfully of voltages of the order of 500 000 volts.

There are two small questions which I should like to ask. First of all, with regard to Fig. 2, is it not proposed to connect the Donsoda power station in the Ukraine to the Kharkov power station by a 110-kV line? Secondly, the fifth column in Table 2 is headed "Average installed generating capacity"; I am not quite clear what that means. Possibly it is the average for the year, where a station is being rapidly extended.

Mr. R. H. Abell: The immense electrical activity in Russia is demonstrated by the growth of load as shown in Fig. 1, and I have as a matter of interest plotted our own figures in a corresponding curve. (Mr. Abell here exhibited a lantern slide.) This shows that the two lines cross in 1932, so that Russia is now ahead of us in total output; but for 1933 the Russian figure of kWh per head of the population is about 90 compared with Great Britain's 310, calculated on the Commissioners' returns only, so that on this basis Russia has still a long way to go.

I am interested in the great variety of fuel used in Russia—oil, coal, peat, natural gas, brown coal, and industrial refuse; the latter, I think, is the anthracite waste to which the author refers. From a book of statistics I see that over 183 million kWh of energy were produced from firewood in 1933. I conclude from Table 6 that a large amount of this energy has been generated at Archangel.

The thermal-electric stations, used both for industrial purposes and for supplying hot water, are increasing in number very rapidly in Russia. American experience seems to show that the supply of hot water is not a very profitable service, but we can no doubt assume that profit in Russia is not of very great importance. The hotel in which I stayed in Moscow was supplied with hot water from a nearby power station, and the supply was ample and always very hot.

Nearly all the stations mentioned in Table 6 seem to be base-load stations, and those round Moscow are already interconnected by a 110-kV network. This no doubt provides facilities for loading and makes possible the high load factors mentioned in col. 7 of the table. In the same way, the marked improvement in load factors of the principal stations in this country has been brought about to a considerable extent by the operation of the grid system. There is no doubt that the abolition of Sunday in Russia has improved the load factor, and I am told that there is now only a 20 per cent variation in the daily maximum demand in Moscow.

The few outdoor 110-kV substations which I have seen round Moscow do not seem to differ in general design from the high-type substation used in this country. In Moscow itself there is a 110-kV substation which is built as an outdoor substation but entirely roofed in, with very large bushings (resembling switch bushings) passing through the walls to take in the conductors. This station has certain advantages in regard to maintenance, but it was very costly to construct and I understand that there is no intention of building further substations of this type.

I have already referred to the 110-kV network round Moscow; I find that in 1932 the length of line at this voltage incorporated in the network of the Central Power Board was about 2 700 miles. There is also a similar amount of 38-kV line and about 700 miles of 22-kV line. It would be of great interest if the author could give us some information on the performance of these lines, particularly in regard to snow, sleet, lightning, fog, and vibration. I have observed that where the

transmission lines cross telephone lines no provision is made for guarding, special insulators, or laying of the communication circuits underground, and normal construction appears to be adopted in all cases. The 110-kV line which runs into Moscow follows the course of the river for about 2 miles, and the towers are astride the pavement for quite a long distance. The only special construction used is double tension insulators. Lightning arrestors for the 110-kV and 220-kV transmissions do not seem to be used; it would be very valuable if we could have some further information on this point.

Mr. W. S. Burge: It would be of interest if the author could give some information on the co-ordination of the Russian power schemes from a loading point of view. Are the stations concerned operated under the direction of one or more central control rooms? If so, it would be interesting to have an outline of the manner in which this is carried out.

The section of the paper dealing with thermal-electric stations is particularly interesting, although it is not likely that this sort of application would meet with any commercial success in this country. In the United States the majority of such schemes make use of steam, not water, for heating, and in one or two instances in the U.S.A. it has been suggested that pass-out turbines could be arranged to serve for pressure boosting in suitably located substations. The major claim for this suggestion is that by means of such steam substations the distribution area of the steam mains could be extended almost indefinitely. It would be interesting to know whether any such scheme has been considered in Russia.

Towards the end of the paper there is a particularly interesting reference to the efforts being made in the U.S.S.R. in the direction of standardization. I notice that the authorities in Russia have selected rather higher steam pressures than we are using in this country, but their pressure of 810 lb. per sq. in., coinciding with 850° F., is quite practical, and will probably give good results. The indication from these steam conditions is that Russian engineers have taken the maximum advantage of the pressure scale without involving the necessity for reheating. In a country such as Russia there is naturally great opportunity for standardization, and it is probable that Russia's efforts in this direction will meet with considerable commercial and technical success. In the older and more intensely developed countries of Europe, as also in the United States, efforts at standardizing steam conditions and unit capacities have not met with much favour. While a member of the International Electrotechnical Commission in 1926, I took part in discussions on the subject of standardization. Although the members of this Commission agreed unanimously on the value, both commercially and technically, of standardization, it was equally agreed that any effort to force such standardization in the United States would meet with failure. It was felt that the desire to be a pioneer in the direction of higher steam conditions or larger unit capacities, would render any such efforts abortive.

Mr. L. W. Phillips: The story of Russia's development in electrification is an epic of modern industrialization, and it should be an incentive to British industry by showing what can be done by initiative and courage in overcoming tremendous odds. Facing as we do a slump in industry and a large amount of unemployment in this country, if we could only share some of the same spirit progress would be rapid. One almost wishes that Sir Archibald Page could have some of the powers of a dictator, such as Trotsky had, in order that he might move the electrical industry in this country. We seem to be content to visualize an all-electric house, but Russia looks forward to an all-electric country, and I think we should hold something of the same vision.

I am particularly interested in the author's remark that Russia will soon be in a position to supply all her own electrical needs. I think it would be a great pity if British electrical engineers took that as an indication that no trade is to be done with Russia. I think there is every indication that there can be a vast trade with Russia in electrical equipment. The population of Russia is more than four times that of this country. Her population is largely of the peasant class. It has to be industrialized, it has to be taught technique; and, although Russia has a large number of research workers, she still lacks a large number of people who can put to practical use the results of research. In consequence of the type of organization in force there, Russia does not create a demand for industry, and if orders are to come to Great Britain she herself will have to create that demand. The spirit in which we must approach Russia should not be the spirit of a great commercial country seeking to trade for its own gain; we must feel that we as British engineers have something to offer Russia. She is very desirous of being up to date, and, if British engineers can produce new and more efficient plant, Russia will be responsive to that appeal and will trade with Great Britain.

We have always been unwilling to approach people in their own language, and if they could not speak English we seemed to think they were not worth considering. If we are going to do business with Russia, however, it necessarily means that we have to be prepared to undertake a great deal of publicity in the Russian language. I think we should try to get our share of Russia's business, not for the sake only of our own industry but also for that of building up a country which has done so much for herself.

Mr. A. Volin: In regard to the part played by peat in the development of electrification, I should like to point out that it is not only the extent of the use of peat but also the capacity of the boiler units that have reached a very advanced stage of development. For example, the boilers of the Dubrovka station have a maximum capacity up to 200 tons of steam per hour, and are equipped with chain grates with a surface of 100 square metres working with preheated air at 250–300° C.; such units are amongst the biggest ever used.

Another important question is the utilization of anthracite dust; the Soviet engineers could not take advantage of the experience of foreign technicians in this direction, as in no other country has this kind of fuel been used at such a low ignition point as in Russia. English and American anthracite is much richer than that of the Soviet Union. Attempts to utilize this fuel on chain grates have shown a loss of 50 per cent or more. The problem was solved when a method of burning the dust

as pulverized fuel was found. This method, which is only a wider introduction of the use of anthracite dust, at present supplies more than 500 000 kW. The loss due to incomplete combustion at the present time only amounts to 4–6 per cent, and the boiler efficiency reached at some stations (e.g. the Zuevka station) is 80–85 per cent.

As a result of the State planning of industry, it was decided to utilize the better-quality fuel in the metallurgical industry and in transport. The electrical industries were therefore faced with the problem of utilizing only low-quality fuel, or the waste from high-quality coals. It is evident that such a utilization of fuel is to the greatest national advantage. At present about 70 per cent of the regional electric stations work on such fuel. The majority of power stations are working on pulverized coal and have introduced an individual fuel preparation instead of the centralized form used previously in the big stations. It should also be mentioned that, for the first time on a large scale, the drying of coal having up to 35 per cent moisture has been introduced in Russia. This is not done in the central drying plant, but by suspension in special tubes forming part of the whole milling equipment; this is the so-called Rema-Rosi principle.

The following figures, not given in the paper, indicate the main power sources of the stations: Stations working on local low-quality fuel, 70 per cent; hydraulic stations, 10 per cent; transported fuel, 20 per cent.

The author devotes considerable attention to the thermal-electric stations; I should like to point out the main differences between the Soviet and the New York thermal-electric stations. While the stations in New York are essentially district heating stations, not producing electric power, the Soviet stations work on a combined principle of supplying steam to the consumers only after this steam has been utilized in the turbines for the production of electric power. Owing to the long distances, the heat is not conveyed as steam, but as water heated by the utilized steam. This combined method, as is well known, raises the efficiency of the best condensing stations from 25 up to 60 per cent. The combined production of heat and electricity is the dominant tendency of the modern generating stations. This principle is the basis of the development of industrial and municipal centres, and it is also being introduced into the big towns. The total capacity of thermal-electric stations at the present time is more than 800 000 kW. The desire to produce the maximum amount of cheap electric power necessitates the use of steam at pressures of 100 atmospheres and upwards, which is particularly economical from the point of view of thermal-electric stations. In this regard the thermal-electric station in Moscow, which works at a pressure of 125 atmospheres, is an important development in Soviet electrification.

The author devotes considerable attention to the question of standardization. I should like to add that owing to the standardization in 1934 alone it was possible to introduce, in about 15 stations, standard boilers of 110 and 250 tons of steam per hour respectively.

The "spectacular development" in electrification mentioned in the paper was only possible as a result of the consistent carrying-out of a planned system which embraces all branches of national economy, electrical power being one of its essential parts. This planning, which is completely concentrated in the hands of the State, has made possible: (1) The most rational distribution of electrical stations and grid system in accordance with the economic requirements of the country. (2) The completion of new stations and reconstruction of old stations on a basis of utilizing the kind of fuel which is most essential for the national economy. (3) The organization of industrial and municipal building on the basis of supplying power and heat at the same time. (4) The organization on a strictly standardized basis of the production of electrical equipment.

Mr. A. N. D. Kerr: This paper should be of considerable interest to electrical engineers in the Irish Free State, by reason of its reference to peat fuel and to the enormous strides made in a country only partially appreciating electricity. I do not want to encourage unduly the use of peat fuel in the Irish Free State, but merely to see development in the use of every type of fuel.

The particular point which I wish to bring to the notice of the author is that brown coal occupies an intermediate position as regards calorific value, volatility, and moisture content, between peat and ordinary coal, and I believe that in Germany considerable progress has been made in the burning of brown coal or lignite. German engineers must therefore have had to contend with the problems which have occupied the attention of Russian engineers. Has Russia been able to learn anything from Germany in regard to the method of application of the coal to chain stokers?

Mr. E. Kilburn Scott: When in Russia about 45 years ago I noticed that in the Archangel district there was a great amount of atmospheric electrification, and it would be of interest to know whether, at the transmission voltage of 220 000 now in use and the 500 000 volts being talked of, corona effect would be rather serious. Will the transmission lines in that district have to be a good deal farther apart than in these latitudes? The references to the Russian thermal-electric stations are most interesting, especially those dealing with the very high efficiency one. Some years ago I referred to* what had been done by a branch company of the Philadelphia Electric Co. at Pittsburg when they closed down small electric stations in the city and gave supplies from their super-stations at Brunot's Island and Colfax. They did not take out the boilers but used them for supplying steam heat to public buildings, restaurants, hotels, apartment houses, etc., in the city. This is as profitable as selling electricity. We have 550 power stations in this country, and I understand that it is proposed to reduce their number to about 135. A lot of boiler plant which has not long been in use will therefore be scrapped unless a use can be found for it. Why should it not be used to supply steam heat, or, alternatively, heated water as in Russia? Will the author please say why Russiahas adopted 110 000 and 161 000 volts, instead of 66 000 and 132 000 volts as in this country?

[The author's reply to this discussion will be found on page 640.]

* *Journal I.E.E.*, 1931, vol. 69, p. 1101.

MERSEY AND NORTH WALES (LIVERPOOL) CENTRE, AT LIVERPOOL, 7TH JANUARY, 1935.

Mr. B. Welbourn: The paper reveals a national electrification scheme planned as a whole and planned for dealing with virgin territory. There is practically no scrapping of existing plant to be done, and full advantage can be taken of the standardization and experience of other countries.

This huge enterprise has been planned not only as an electricity supply undertaking but combined with it are the necessary research organizations and the works in which all the plant required can be built. It is quite clear that Russia intends to be as self-contained as possible and that, before long, the imports of large electrical machinery from England and America and Germany will cease.

Russia finds it difficult to get money to pay for her goods. In connection with the electrification scheme and in other directions she is using her assets to the best advantage: for her power stations she is using her peat and her water. What is the cost per kilowatt for the plant installed in the various Russian power stations? I would also ask for information about the thermal efficiency of the peat-fired stations, the terms on which electricity is supplied in bulk and to the domestic consumer, whether all private generation of electricity is forbidden, and what steps are taken to encourage the use of electricity.

Russia possesses good engineers; in this connection I would mention that the first power station which I ever saw in Russia, about 1911, was the oil-fired station in St. Petersburg (now Leningrad). It was a wonderful revelation to see the boiler house, which was just as clean as an ordinary living-room.

The development of the use of the peat and brown-coal resources of the country is on a very large scale and, so far as I know, the only other comparable developments with brown coal are those at Morwell in Australia, and in Westphalia. It would be interesting to know how the brown coals in different countries compare in regard to calorific value.

Can any information be given about the experience gained in running these large power stations in parallel and also in operating the transmission lines—particularly from the lightning and ice-loading points of view?

Mr. E. B. Pausey: I am impressed by the unexpected amount of organization and originality which the Russians seem to have been able to devote to this, to them, entirely new problem. The paper throws an entirely new light on our view of conditions in Russia. A nation which in recent historical times has been almost entirely agricultural seems to have changed its mental attitude towards technical matters in a most unexpected way.

With regard to the use of peat, I am especially interested in the type of furnace illustrated in Fig. 4, but I should like to ask whether there is not an unnecessarily large loss of efficiency in the design. I imagine that a good deal of the air entering at the bottom of the chamber would tend to pass beneath the combustion zone in a separate stratum without mixing to an appreciable extent with the combustible matter, and so would undesirably increase the percentage of excess air. The application of secondary air in such a manner as to set up turbulence would probably be a great improvement. Further, I should like to know how these furnaces are lit; the ignition of pulverized coal in a cold combustion chamber is not always easy, and with such a fuel as milled peat the difficulty would probably be greater.

Another question I should like to put concerns personnel. Whence have the Russians obtained their technical force, particularly the general rank and file? Here one is up against the difficulty of taking agriculturally-minded people and turning them into engineers in a short time; it seems to me that this must have required great perseverance and patience on the part of those responsible for it.

Prof. F. J. Teago: What has been done up to date certainly shows that Russia must have an enormous store of potential energy. I want to talk about peat burning, which, to my mind, is one of the most interesting subjects discussed in the paper. Russia seems to have partly solved this difficult problem. It is interesting to note that 42 per cent of the world's peat supply is located in Russia, mostly in the European parts, and that some 30 460 million tons of this fuel, calculated on a basis of 7 000 calories per kg, are available south of the 60° latitude line. Another interesting point is that the peat used at the Shatura station has an average fuel value of 3 500 calories per kg, which is quite a reasonable figure. I am rather sceptical about peat from the tundra, since the tundra lands are frozen solid most of the year. I should think it would be difficult to get fuel from them, except perhaps surface material like turf, during the short arctic summer.

The burning of peat is associated with two difficulties; one is the tarry deposit and the other the ash problem. The author mentions a method of getting over the deposit difficulty, which otherwise would certainly cause serious trouble. I do not agree with him when he says that the ash content of peat is not high, although I admit that some coal shows a higher ash-content. The collection and disposal of peat ash (I am speaking of peat free from sand or gravel) is not easy. The slightest puff of air sets it in motion, and it is extremely difficult to get it to settle down again. How Russia disposes of it I do not know, unless the problem settles itself by a general distribution of ash over the whole town. It would, however, form a good fertilizer if it could be collected and transported easily.

I am very interested in the gas-producer chain-grate furnaces described by the author, particularly as they obviate the necessity for drying out the peat. I cannot, however, see the reason for burning peat on the chain grate as is done in the Makarev process, since the function of the grate should be to remove the ash only. It is not surprising that the Shirshnev system, where the peat is consumed independently of any grate, is a later development, and when this system is worked in such a manner that it allows the ash to settle and be removed by a chain grate the problem of peat as a fuel should be well on the way to a complete solution. I should be glad to know whether any further developments in the burning of peat have taken place since the paper was written.

Mr. O. C. Waygood: On page 623 reference is made to a specification covering paper-insulated cables; could this be added to the paper before it is published in the *Journal*? If it is not possible to give the whole of the specification, extracts indicating the more important points might be given.

Mr. H. Kehoe: The paper gives an excellent idea of the progress of electrification in Russia. The combination of pass-out turbines with the supply of heat to works and dwellings is undoubtedly good, and the overall efficiency obtained of 58 per cent is more than twice that of a plant with straight-through sets. I should imagine that where towns are built round coal-burning thermal-electric stations, grit and sulphur fumes from the stacks will cause trouble, and I should like to know what steps have been taken to overcome this difficulty.

Mr. Noel: Russian engineers have certainly advanced in the last 10 years, but I think their progress has been due largely to engineers who have gone out from various other countries in Europe giving the best of their knowledge, skill, and technical advice, to those working in Russia. The author himself has been largely responsible for much of the technical work entailed in collecting and passing on data to the Russian engineers, who have also given of their best with such knowledge as they had been able to obtain prior to the Revolution.

Mr. J. E. Nelson: I have no question to ask other than those which have already been asked by Mr. Welbourn and Dr. Teago. I too, like Mr. Welbourn, am interested in the financial side of the paper. I should like to have some English figures for the price at which the electricity is sold, and the voltage at which it is supplied to the user.

I am very interested in the use of peat, and I should like to know what happens to the ash; it seems to go up into the air and obligingly does not reappear. Most power-station engineers have considerable difficulty in getting rid of their ash, but in this case I understand there is little ash to get rid of. I should like to ask how much peat there is available. What is the depth of the seam, and to what depth is it necessary to dig to get it? Is there much difficulty in winning the peat, or is it on the surface?

I was very much impressed with the cleanliness of the power station and boiler house shown on the screen; it looked as if it had not been put into operation. I must confess the boiler house at the Percival Lane station suffers by comparison, although I used to think it a clean one.

[The author's reply to this discussion will be found on page 640.]

North-Western Centre,* at Manchester, 8th January, 1935.

Mr. T. W. Ross: The paper is of such general interest that it is bound to attract the attention of engineers in general. For instance, the circulation of hot water throughout the business and residential areas of cities like Moscow and Leningrad, to the extent contemplated, is something new and will introduce problems which in themselves will find work for the engineer. In this connection I should like to know the diversity factor for a heating load of this character.

During one of my visits to Russia there was talk of heating some of the cities by electricity. The heating problem in Russia is largely one of transporting the domestic fuel, which takes the form of wooden logs; but heating from either hot water or electricity has many advantages. It would be of interest to know to what extent the electrical heating of buildings has been proceeded with, and what results have been obtained.

The author refers to the work done in the U.S.S.R. in the field of research; I was much impressed by the wonderful laboratories near Moscow which were in process of being equipped when I was there in 1928. With such laboratories available the electrical developments should be built on sound foundations, and it is this thoroughness in planning which gives confidence in the future success of the various schemes at present in being and which have been planned.

It would be of interest to know the load factors of the hydro-electric generating plants described in the paper. During certain parts of the year there may be a shortage of water, which may affect the annual load factors. It is apparent from Table 6 that the load factor of the steam stations is comparatively high, and it would be of interest to compare the two types of stations.

The developments which have taken place in Russia during the last 10 years have been on a scale never before attempted, and practically all manufacturing nations have contributed to them. This has resulted in some variation, because of the different standards employed in the various manufacturing countries. It will be interesting to note the effect which this will have on the standardization contemplated in the U.S.S.R.; perhaps a compromise will be made in an attempt to get the best results.

The author mentions the difference of opinion which exists among the Soviet engineers on the question of protective gear. There is, of course, nothing new in this; a similar difference of opinion seems to exist in other countries. I have had many discussions on the subject with these same engineers, and I have been much impressed with the thoroughness with which they investigate the problems arising in connection with this important subject. It is also interesting to note that their standard schemes are largely based on British practice, and that they are now manufacturing protective gear similar to that used in this country. In some cases they have had to depart from standard British practice, but this is largely due to system conditions and not to any failure of the British scheme.

Mr. E. C. McKinnon: I should like to draw attention to the important part played by Manchester and Lancashire in the development of Russian engineering industries. Apart from the activities described by the author, Manchester firms have equipped numerous Russian cotton mills with textile machinery and electrical plant. I first visited Russia in 1900, and even then the

* Joint meeting with the Manchester and District Association of the Institution of Civil Engineers.

largest cotton mill in the world (at Narva) was run on water power. The accumulation of ice in the river at a certain period of the year was very troublesome, but in general this did not cause a stoppage of more than a day or two.

The author expresses some doubt about the possibility of entire satisfaction from projected hydro-electric schemes in the north of Russia, well within the Arctic Circle; I would point out that large hydro-electric schemes have been in successful operation for many years well within the Arctic Circle in Northern Sweden.

The enormous development in Russia which occurred during the period 1900–15 was correctly attributed by the Russians to German enterprise, which received a dislocating wrench through the Great War. It would be interesting if the author could give further information about the railway in the north of Russia which was carried for many miles over bogs and morasses, in some cases 60 ft. deep. During construction enormous blocks of concrete were dumped into the bogs, the intention being that as these gradually settled down the level would be maintained by dumping further blocks and also tree-trunks.

Mr. W. Kidd: It seems to me that a lot of trouble must be caused by condensation in the cyclones shown in Fig. 5; the fuel bunker seems to have a double side. Is this the case?

I should like to know whether the use of peat as fuel leads either to any trouble due to dirt in the boilers, or to a reduction in efficiency. If so, what means are adopted for cleaning the boilers? Is the peat ash extremely light, and liable to be carried through and emitted from the chimney? When the ash is dumped outside the station, is it not necessary to take precautions to prevent nuisance due to it being blown about?

In this area we have endeavoured to develop a warehouse and office steam-heating load; but the difficulty and expense of providing pipe-lines through the streets has limited the scope of the scheme.

In Russia, apparently, the conditions are much easier in this respect, and the load factor higher. Presumably the heating business is a 24-hours-per-day load for about 6 months of the year.

Mr. W. E. Swale: There are three main factors in economic development: labour, natural wealth, and capital resources, the latter including the available reserves of administrative experience. With regard to labour, there are in Russia something like 140 millions of people. As regards natural riches the country is probably as wealthy as the United States, and within its borders can be produced everything that man requires, in addition to almost everything required by the heavy industries. The biggest handicap is the lack of skilled directive force, but that will surely, in time, be improved. There is every reason for Western civilization to anticipate that in another century the Russian Republic may be a serious economic competitor, and its development will change the whole social history of Europe.

On the question of natural resources, there must be one or two materials which are not produced in Russia, such as rubber, mica, and possibly chromium; and I should like to know what difficulty the Russians have in supplying themselves with those essential raw materials for the manufacture of electrical machinery.

Another interesting point is the rapidity with which Russian power stations build up their loads. There cannot be much domestic load, having regard to the relatively low standard of living, and apparently the load is built up by intensified industrial development in the neighbourhood of the power stations.

Mr. W. Fennell: The Russian people are acting very wisely in maintaining the policy, even after quite a number of years of development, of sending trial orders to several firms in order to find out which complies most closely with the conditions specified. It seems extraordinary that a nation which was in the condition Russia was towards the end of the War should have been able to build up, not entirely, but certainly to a very great extent, out of itself this industrial organization. It must have been a great shock to many of the people, who had to change their mode of life from purely agricultural to manufacturing.

With reference to Fig. 13, I should like to know whether the bottom section of the pole, which is clamped or braced to the top section, is made of ferro-concrete or of timber on a timber base. I see that the pole embodies all the latest improvements in the way of "kicking" blocks, which the Electricity Commissioners urged upon us very keenly when we were, in their opinion, overloading the foundations. It is interesting to note that the Russian standard specification, to be issued shortly, provides for transmission lines designed to stand the stresses set up by a 20-metre-per-sec. (45-m.p.h.) wind when the conductors are coated with a covering of ice 10 mm (0·394 in.) in thickness. That seems to be slightly lower than the British standard, namely, a 50-m.p.h. wind (8 lb. per sq. ft.) and $\frac{3}{8}$ in. (0·375 in.) of ice. It appears that after the Electricity Commissioners in England have reduced the standard of line construction twice, we still have practically the same thickness of ice and a greater wind velocity specified for our lines as compared with Russia with the presumed worse conditions of snow and wind.

With regard to protective gear, judging from recent experience in this country the Russians are very wise to continue to try out various types of protection.

I should like to ask what is done with electricity in Russia? Who uses it? Do the Russian people pay for it, or do they obtain tickets for a fixed amount of electrical energy per head per week? If there are prices, can the author give us some idea of the figures for heating a large building electrically and for ordinary domestic purposes, so that we may make a comparison with the conditions in this country?

Another query which I should like to put is: Have the Russians yet got to the stage of carrying out rural electrical development?

Mr. J. S. Peck: I noticed, in a report which was published recently, a statement that the Russian authorities had come to the conclusion that what they specially required was engineering and manufacturing technique; the author also refers to this as one of the essentials. The Russians have discovered that no matter how complete and modern the manufacturing equipment may be, it cannot be used to its full value unless there are skilled workers and skilled engineers to operate and supervise it. Thus the major problem facing the authorities in Russia

becomes one of developing their engineering talent and training their skilled workers.

Mr. J. Harcourt Williams: I should like to ask the author whether he can give the cost of peat delivered at the power station, as compared with that of coal. Is there any danger in Russia of the development getting ahead of the demand, as it appears to be doing in the United States?

Mr. W. Eccles: According to the figures for the units generated in Russia for the past 6 or 7 years, the rate of increase of demand is 50 per cent per annum, and this is the reason for the remarkable rate at which power stations have had to be constructed. Experience arising from such rush work is always beneficial, as the decisions must be made with a minimum of discussion. It is surprising how little we in this country gain in the end by spending very much longer before arriving at a decision; many of the possible difficulties are not realized in practice, and money so spent in averting them is wasted and the plant complicated to an unnecessary degree. It is a pity that most of this valuable experience is lost to all except those directly concerned.

One side of the subject which the author just touched on was that of the appearance of the power-station buildings. The Shatura station, although located miles from anywhere, is the finest building of its type I have ever seen. It seemed to me as though the whole lay-out had been conceived by an artist. For instance, at the main entrance to the station there was an excellently proportioned octagonal fountain located in the centre of a grass plot. It appeared on investigation that this was the air washer for the station ventilating air, the ducts being carried below ground. On going into the boiler house one found an extraordinarily well-lit lofty room, having a floor tiled with large black and white tiles. On the left was a series of very large well-proportioned bay windows which accommodated feed pumps and instruments for the boiler opposite. Many details, in particular lamp brackets, were well worth examination, and yet everything was simple and, as it had to be, easily made. This is a feature of station design which we could not do better than copy.

Mr. M. Whitehead: Can the author tell us what proportion of the electrical energy produced in Russia is used for domestic purposes, and what proportion for industrial purposes? He stated that, in the case of one station at least, there was no load when it was built, and works had to be erected all round it in order to use the energy.

In the list of manufacturing concerns two meter manufacturers are given; is their output sufficient to meet the number of consumers?

Mr. B. L. Goodlet: In 1919 the largest machine which had been constructed in Russia was a 250-h.p. motor. Fifteen years later the same works were constructing some of the 77 500-kVA units for the Dnieper station, which are the largest waterwheel alternators yet built. Progress of this kind does not appear so remarkable when it is remembered that the drawings and supervision for much of the work are supplied from abroad.

The development of our own aircraft industry during the period 1914–19 is, in my opinion, a much greater achievement than any work which has been done in Russia to date; and I feel that we have no reason to shrink from comparison.

From Table 6 it would appear that the generating plant in the Moscow district runs on a continuous overload for about half its working time. I should like to know how this treatment reacts on operating reliability.

Mr. Eccles has expressed great admiration for the architecture of Russian power stations. Personally, I regard sanitary arrangements as more important than tiled floors and fountains. In my own recollections of the country, dangerous drinking water, imperfect sanitation, bad drainage, and verminous buildings, loom very large. Electricity is of course a great thing, but I should like to know how these other amenities of civilized life are progressing under the Plans.

Mr. R. W. C. Alford (*communicated*): Can the author give me some idea of the extent to which telephone communication has been developed in Russia? I feel certain that the effort for rapid development of industry could not have materialized without the service which the telephone system provides.

[The author's reply to this discussion will be found on page 640.]

East Midland Sub-Centre, at Nottingham, 15th January, 1934.

Mr. R. H. Redmill: Would the author give us some information as to the method of co-ordination between the Russian central electrical authority and the small towns of far outlying areas?

Mr. D. C. Rushworth: The author makes reference to the construction of the inland canal; were any excavators used in this work, or was the mass labouring system employed? He also refers significantly to the year 1937; is that the date of the end of the Second Five Year Plan? The irrigation scheme is interesting; it would appear possible, however, to irrigate by means of reservoirs constructed in suitable surroundings, using ordinary flow conditions.

Mr. J. Engblom: It would be interesting to know the source of the money with which Russia purchases her electrical equipment. How are the necessary credits, for example, in England, created, seeing that there do not seem to be any large imports here of Soviet products?

Further, as only a very small percentage of the Soviet subjects are in the position of being able to pay taxes, how is the cash raised to balance the budget for wages and materials necessary for these schemes in the U.S.S.R.? This problem does not seem to be an easy matter, even in countries where the Chancellor of the Exchequer avails himself of every possibility in this direction.

Mr. A. Brookes: Is there any technical reason for the author's statement that the maximum efficiency with peat firing is given at a moisture content of 32 per cent? This effect cannot be due to the formation of water gas and its subsequent burning, as suggested, because the energies of dissociation and formation would balance unless the former were obtained from heated parts of

the furnace normally giving a less transference of heat to the energy production of the furnace.

Mr. A. Marsh: The particular item of the paper that claims my attention is the use of anthracite waste in powdered form for steam generation by the power stations in the U.S.S.R. I believe that considerable difficulty has been experienced in this country where that grade of fuel has been tried. I should be interested to know the method of lighting up the fuel, the type of burner used, and whether a luminous arch is necessary to maintain ignition. The new Tir John power station, Swansea, will be using anthracite duff for steam generation.

Mr. E. W. Porter: Can the author give us any idea of the cost of peat, and its value when passed to the boiler? How does it compare with coal under comparatively similar conditions? These comparative values might give a basis on which other peat deposits could be assessed.

Mr. J. N. Henshaw: I am rather interested in the plan of using electric traction to get over the trouble of braking on the long down-gradients, by using regenerative control. I should think this system would be more than self-supporting, and I am anxious to know whether that is the case.

Mr. C. A. Brearley: I should be glad if the author would give further information on the following points: (1) Is research organized on an institutional or competitive basis, i.e. is a problem usually given to one institution specially selected and equipped for a particular line of research, or is it passed for solution to several institutions? (2) What method of selection is adopted in choosing men for training for higher posts? (3) Are skilled craftsmen trained on an apprenticeship system? (4) Has a system similar to our war-time munition workers' short-period training scheme been adopted for the training of single operation workers engaged in mass production, or does each factory train its own workers? (5) Does the U.S.S.R. co-operate in the formulation of international technical standards? (6) Are the wooden poles, used in transmission lines, treated? (7) What is the order of the gradients referred to in the paper where electrification has been adopted to overcome braking difficulties? (8) Is there in general a standard railway gauge throughout the U.S.S.R.?

Mr. J. F. Driver: The paper indicates the extraordinary electrical developments taking place in Russia, and it shows that our colleagues there must be controlled by some authority having foresight and ability.

I am particularly interested in the description of the thermal-electric stations; in this respect the Russians have acted extremely wisely. I always feel that a good case can be made out for the "central station idea," in which the generating station supplies not only electricity but also low-grade heat in the form of hot water for process work and for general heating. I visualize the time when electricity stations will occupy the centre of a large piece of land surrounded by factories. Unfortunately the present idea often appears to be: "Here is a big river, let us erect a generating station." Under these conditions millions of heat units are literally thrown into the river. Will the author give us some indications as to the methods whereby heat is utilized?

He gives particulars of high-tension distribution schemes operating at various voltages. With our own grid system in mind the question naturally arises: Why not uniform transmission voltages? I take it that owing to the immense distances between stations there will never be any question of interconnection, but it would be interesting to know if local conditions were taken into consideration when choosing the transmission voltages.

The section dealing with the utilization of peat for power purposes indicates that this fuel has many excellent properties, and it would be interesting to know if stations in Ireland could be erected to run economically on peat.

The author uses C.G.S. units throughout the paper, and I am afraid many engineers require these to be mentally converted before they can visualize the state of affairs. I suggest that it would have been better if the values in British units had been placed in brackets alongside the metric units. For instance, on page 609 the author refers to mega-calories; I feel that a large number of those present would prefer to have seen these values expressed in B.Th.U.

Mr. A. R. Hayes: Regarding the method of insulating the hot-water pipes which circulate through the streets, apparently the temperature is very low at various times of the year, and it would be interesting to know what type and method of insulation is used. It would also be interesting to know whether the technicians employed on the electrical development of the U.S.S.R. have been Russian, or whether European or other engineers have been at the back of the organization.

[The author's reply to this discussion will be found on page 640.]

North Midland Centre, at Leeds, 22nd January, 1935.

Mr. W. Dundas: The rate of development of Russia's electricity supply during the past decade has been remarkable. It would be interesting to know the underlying factors responsible for the extraordinarily high load factor. Details as to tariffs would also be welcome.

Two of the many striking features contained in the paper are the reference to the use of peat fuel and the development of thermal stations. The utilization of peat deposits in this country has been suggested on various occasions, and the reasons for its dismissal are fairly obvious. The consumption of peat on the scale indicated by the author must present great difficulty: to obtain the requisite quantities of peat over a very limited period of the year necessitates the part-time employment of a large body of men, and unless such labour can be absorbed in other directions the true cost of the fuel will be greater than the figure given in the paper. The thermal results obtained with peat compare favourably with those of other fuels, and the relatively low ash content has made the use of short stacks possible even when firing with pulverized peat.

The utilization of low-grade heat for domestic and industrial purposes is an ideal to be aimed at, and it would be of interest to know how much of the low-grade heat available from the 75 000-kW station it has been found possible to utilize outside the station. Such

schemes have been tried out in America and also in this country, using low-pressure steam instead of hot water, and it has been found that the requirements of the two services—electricity and steam—do not fit in very well; this is readily appreciated when one considers the effect of seasonal variation on the demand. The two services have therefore been operated more or less independently. The capital cost involved in heat transmission is very considerable, and reflects on the economic price obtained for the heat. Information regarding the economic aspect of the scheme referred to in the paper would be of interest. It is somewhat surprising to note that it has been possible to lay the heating pipes so near to the surface of the ground; I should have thought it advisable to go beyond the reach of frost penetration.

Mr. F. Gurney: Russia has been most interesting to us from the time we first heard of the Five Year Plan. I think we must agree that from the electrical point of view Russia has some men of vision. It is a country without engineering traditions, especially without traditions of experience, and I imagine that the men who are responsible for the schemes described in the paper are of the university professor type. It is to be presumed that they themselves unaided have not carried out all the schemes. They have presumably bought experience from other countries like America, Germany, Sweden, and Great Britain. It would be interesting to hear from the author what would have happened if the university professors had been without assistance from people with practical experience. Great credit is due to the Russian engineers for the way they have tackled the problem of burning peat. They have worked hard and have undoubtedly met with considerable success in a problem which was entirely new, probably to the whole world. They are also possessed of wonderful ideas; for instance, I notice that one of the standardized sizes of turbo-alternators is 222 222 kW. They have achieved wonderful results with low-ebb water power, and have succeeded in damming the Volga two or three times.

The maximum voltage of any alternator mentioned in the paper is about 15 000 volts. This is an interesting point to British engineers, who have held various views on the matter. Is that voltage the maximum decided upon, instead of the 33 kV suggested in this country?

I am interested to find that spliced wooden poles are used on the high-voltage transmission lines; I have not seen many in this country, and it would be interesting to know whether they have been found successful in Russia.

The author mentions a short-circuiting testing station with an alternator rating of 50 000 kW. Presumably it has another short-time rating which will enable Russian engineers to carry out tests up to 1 million or so kVA like plants in this country.

I should be interested to know what voltage has been adopted as standard for low-tension distribution in the industrial works. Is it 400 volts, or has a more sensible voltage such as 600 volts or more been chosen?

Mr. R. M. Longman: Little mention is made by the author of difficulties respecting the rupturing capacities of the oil circuit-breakers on the larger systems; it is noted that in many cases the generators are connected straight to step-up transformers. Have troubles been experienced owing to freezing of oil in switches or transformers, or to ice or snow on the overhead lines and isolators? A further item of interest is that the voltage of the generators which are connected directly to the step-up transformers is apparently 13 800, which is nearly the same as that for the 50 000-kW sets at Dunston.

Great credit is due to the Russian and other engineers for the way in which they have tackled the problem of the collection and utilization of peat fuel. I believe consideration has been given to this problem by British engineers with a view to making use of peat deposits in Ireland and Scotland.

I should like further particulars regarding the consistency, constitution, and calorific value, of the anthracite spoil.

Further information would be of interest respecting the daily and yearly load factors obtained, and how the latter compare with the values of 35–40 per cent prevailing in this country. The chief need is, of course, a good night load. Table 7 gives figures of fuel costs but not of repairs and maintenance or total works costs; the latter would be most acceptable.

Wood poles for the big overhead lines appear to have been used with success; have many cases occurred of such poles being burnt down by fault currents? Has any experience been obtained with the use of treated wood for outdoor insulation?

I note that there is still one problem to be solved in connection with the electrification of 1 400 miles of the Siberian railway—the problem of how to transmit energy at least 700 miles, i.e. from each end.

Mr. E. Kilburn Scott: An interesting part of the paper is where the author refers to those Russian thermal-electric power stations which approach an efficiency of 60 per cent, or about double the best in this country. This achievement is due to the steam being put to another purpose besides that of generating electricity. Improvement in efficiency due to dual use of steam has been known for years, and there are many successful factories using process steam heat obtained from their own electrical plant. In spite of the competition of the grid, isolated or independent plants are being manufactured and sold in large quantities. It is, in fact, high time that the electrical supply business took a leaf out of the book of the gas industry and recognized the advantages of supplying by-products.

Mr. S. R. Siviour: Referring to the author's remarks on standardization, and having in mind that Russia intends to be self-contained as far as possible, I should like to know whether she is creating her own standards or is following the international recommendations. The author refers to Russia's adoption of 10 sizes of turbines as against the internationally recommended figure of 13; does she follow the international ratings for these 10 sizes? Also, does Russia follow the International or Continental standards for transformers, switchgear, and other plant? Are there difficulties in the operation of outdoor switchgear and transformers: for instance, do the exceptional weather conditions prevent the use of air-break switches or other forms of sectionalizing equipment? What is the experience of Russia in regard to ice and snow loading on overhead lines?

Mr. H. P. Bramwell: The author has shown that intensive electrical development has been carried out in the large industrial centres. Living conditions in the agricultural districts are generally primitive, and it would be interesting to know whether any extensive scheme of rural electrification is contemplated.

[The author's reply to this discussion will be found on page 640.]

Scottish Centre, at Edinburgh, 26th March, 1935.

Mr. E. Seddon: Before the War I spent a little time in the Balkan provinces, and I knew some of the difficulties of getting suitable skilled labour in that country. I am therefore interested to know how in these modern days the author was able to find a sufficient number of skilled workmen to satisfy his requirements. May I also ask how the Russian authorities managed to find the necessary number of machinists to operate the plant in the large engineering works referred to? It would have been interesting if a portion of the paper had been devoted to the burning of oil fuel, which, I understand, is available for power stations in certain parts of Russia. The electrification of the railways will no doubt make a large demand on the power stations in a few years, and I should like to know whether a standard system has yet been decided upon for the whole of the railways; if so, the technical details would be of considerable interest.

Mr. R. M. Charley: I should like to ask the author whether he can give any information regarding something I heard in Germany about 4 years ago. In Berlin at that time there were definite rumours of schemes being prepared in Russia where power had to be transmitted over exceptionally great distances, and they were proposing a scheme using 300 000 volts direct current.

Mr. J. Eccles: Progress on the manufacturing side has been remarkable, considering the very limited number of skilled workmen in Russia. I presume that the initial work was carried out by a skeleton staff of foreign engineers who trained local operatives in order to enable them to turn out some of the admittedly good work that they have done. It is of course all very well to erect power stations and get them running, but what happens when the erection staffs leave? There must then be some difficulty in operating stations of 200 000 kVA capacity without a properly trained staff.

A point of interest which follows from the author's remarks is that, seeing that nearly all the electrical output is used for industrial purposes, how is it that the other industries have not kept pace with the electrical side? If the power used in those industries has equalled or exceeded expectations, and the output of the same industries has fallen short of the planned programme, there must be inefficiency somewhere.

Dr. J. B. Todd: I should like to ask the author to tell us something about technical education in Russia, particularly how the young engineers are trained and how the staff is developed for the research laboratories. Is research work confined to State laboratories, or is such work being done in universities as well? My own experience is that everyone who is teaching in a university or technical college is somehow expected to be doing research work. I sometimes get into trouble for suggesting that it does not follow that a man is good at research simply because he is teaching; I have found that the man who is good at research is not necessarily good at teaching. It seems to me that the real research worker should not be required to devote his attention to the routine work of teaching, which is an entirely different matter from research. While it is desirable that teachers should have some time for research, and should be in close touch with the research which is being carried on, I think it is most important that research departments, staffed by specially suitable men, should be established, and I should be glad to know what the outlook is in Russia in regard to this line of work.

Mr. P. M. Colvin-Smith: I should like to ask whether the author can give us any idea of how many electric cookers are in use in Russia.

Mr. G. Henderson: Am I to understand, from the author's remarks, that in general the power stations erected in Russia from 1921 to 1928 were installed by Russian professors to designs suggested by American or Continental manufacturers? Apparently the new stations erected since 1928 have been designed, and the plant manufactured in many cases, by the Russians themselves. Are those factories which are State-owned designed by the Russians, and is all the equipment designed by them, or is the latter purchased from some American, German, or British firm? It seems to me practically impossible for the Russians in the short time that has elapsed to have designed alternators of 70 000 kVA; or did they send a few trained men, provided with the necessary instructions, to take measurements of machines supplied by other countries? Many Russians have been receiving technical education in Great Britain, Germany, Switzerland, and other countries, during the last 15 or 20 years, and Russia's problem must have been solved through those men going back to Russia and developing the electrical industry.

Prof. M. G. Say: Much surprise has been expressed at the magnitude of the tasks that the Soviet has set itself, but the Russians must not be looked upon as in any way technically inferior to the Western Europeans: that is a fatal mistake. The Japanese have taught us to respect the engineering achievements of Eastern races. In fact, it would seem easier for the latter to acquire our technical ability than for us even to appreciate—not to say understand—their culture and tradition. The Russians, with their country linking East and West, may well have the world's progress in their own hands for the next century. That they have produced men of first-class scientific attainments is common knowledge.

It is gratifying to observe the Russians' faith in intensive research, and there is no doubt that the shortage of skilled staff will be rapidly made good. The suggestion for the electrification of the Trans-Siberian Railway looks rather courageous. The distances are immense, the traffic light, the track unprotected, and the population along the route sparse, at any rate at present. It would be of interest to know what particular aspects of the scheme have brought electrification into consideration at all.

Mr. R. S. Ryburn: In Table 7 the generating costs for various power stations are given at an average value of about 5·768 copecks per kWh, which, according to the 1932 rate of exchange, corresponds to about 1d. per unit. This is extremely high, but, as pointed out in the paper, the official rate of exchange bears little relationship to internal prices. Can the author give any explanation why these costs are higher than what we should expect in this country? Turning to Table 11, I see that the average steam consumption works out at approximately 10 lb. per kW per hour. Has this figure been achieved in the power stations now running in Russia, or been improved on to any extent?

[The author's reply to this discussion will be found on page 640.]

SOUTH MIDLAND CENTRE, AT BIRMINGHAM, 8TH APRIL, 1935.

Mr. H. B. Bailey: It would seem that one of the principal difficulties which beset the Russian engineer to-day is an acute shortage of skilled labour for both the production and the operation of plant. Has the author found that this has led to the development and adoption of any special production methods or special designs of apparatus with a view to facilitating the employment of the relatively unskilled labour available?

Mr. A. E. Farmer: I am surprised to learn that the Russians get 85 per cent efficiency from peat-fired boilers. It opens up a new point of view to note that the moisture in the peat is used to develop water gas which is burnt in the boiler, so increasing the efficiency.

Major A. M. Taylor: I cannot see why we should not follow in India the example set by Russia in regard to electrical development. In India there is unlimited water power in certain districts where industries are lacking, and if the water power were dealt with in the same way as in Russia great manufacturing areas could be started. It would be interesting to know whether originally the Russians bought large sets from this country, took them to pieces, made replicas of all the parts, and assembled them.

Mr. R. H. Rawll: I am very interested to note the extreme importance which the Soviet authorities attach to research. The author stated that their large research institutes were staffed by a large number of university-trained men; I should like to know whether these men are sent to other countries for their training, or whether they are being trained solely in Russian universities.

With regard to the question of lamp manufacture, we are told that 40 million lamps are turned out annually by one factory. Has this figure any dependence on the life of the lamps?

Mr. R. Dean: I am particularly impressed by the fact that, in a huge country such as Russia, such enormous developments can be made almost secretly. I should like to ask the author whether the social progress in Russia is as extensive as the engineering progress.

Dr. C. C. Garrard: I should like to ask a question regarding the accountancy side of the new electric stations in Russia. How are the costs of the Russian power stations dealt with? The main item of cost in a power station is the capital charges; how are these dealt with in the accounts?

I am also very interested in the very high boiler efficiencies shown in the peat-fired stations. Could the author tell me how these compare with those of the somewhat similar brown-coal-fired power stations in Germany? The boiler efficiency of the latter is, if I remember rightly, very low indeed.

Turning to the question of traction and of the two lines which have been electrified because of the gradients and the need for regenerative control, have the Russians considered the possibility of using grid-controlled mercury-arc rectifiers to enable this regenerative braking to be carried out?

On the question of transmission lines, I am very interested indeed to find that Russia has followed the example of this country with regard to the switchgear in connection with the grid, and has paid us the compliment of copying our method of protecting transmission lines. I should like to know what degree of reliability the Russians have obtained on these transmission lines, and the percentage of failures they have experienced as compared with those in Germany, France, and America.

The paper deals mainly with the development of heavy electrical engineering; I would ask whether the manufacture of domestic electric appliances is growing in Russia, and whether there is any possibility of an export trade to that country of such apparatus.

Prof. W. Cramp: The successful use of peat in boilers of such high efficiency is a matter of importance to Yorkshire and to Ireland. Years ago in Ireland great efforts were made to use peat as a fuel for producer-gas plants; some of these were put to work and are still running, I believe. I myself made a report upon the use of peat at that time, but the great difficulty was always that of drying the peat. It now appears that moisture in the peat, amounting to 30 per cent, is not disadvantageous in a boiler furnace. That is quite a new idea. Have the Russians considered the use of peat in producer-gas plants, and have they had to give it up because of the moisture? The author states that peat can be dried in Russia in 2 months; we could not dry it in England in 2 months, and any artificial drying was found to be a failure. Would not the "macerating" process tend to introduce still more water into the fuel?

I propose next to refer to the loans forced upon a public that is going to benefit by the plant to be installed. While it may be a bad thing to limit the liberty of the subject by preventing him from investing his savings where he pleases, in the long run will not this plan work out satisfactorily in that the actual producers are interested in the concerns which they have produced? Are not the Russians doing exactly what certain up-to-date firms are doing in this country, namely encouraging those employed in the local industry to invest in that industry, so that they may be less likely to interfere with the industry by strikes? Will not this plan bring ultimate peace in industry, although it may seem at the moment to be curbing the liberty of the people?

Referring to the matter of coiled-coil lamps, I was told to-day, and the author's remarks seem to confirm

the statement, that these lamps might not have been available here even now but for the possibility of such lamps being sent from Russia and elsewhere on the Continent. Is it true that in this country we have been compelled to use lamps which the Russians began to abandon 3 years ago? If so, it would seem that liberty may be curbed in many different ways!

Dr. L. G. A. Sims: I should like to recall some of the conditions I met with when in the North of Russia with the author 16 years ago. The largest set I saw was of about 30 kW, belt-driven from a small engine, the steam being supplied from a locomotive-type boiler. Furthermore, the advanced experimental work which the Russians appear to be carrying out on railway electrification is remarkable, because at that time the railway conditions, at any rate in North Russia, were almost pathetic. I should like to know if the author can tell us what scheme is likely to be finally adopted for railway electrification, and whether it will be carried to the northern parts and to the Archangel region.

Mr. L. F. Jeffrey: As one who is engaged in the design and construction of electric generating stations, I was particularly interested in the time taken to erect these stations. I think figures of 19 months and 27 months were quoted, and as it would appear from the slides that the buildings were constructed in reinforced concrete I should imagine that construction would be limited to a very few months of the year, in view of the winter conditions. Perhaps the author could give us a little more information on this subject. I was interested to know that drawings could be produced in $3\frac{1}{2}$ weeks by the contractors. Another point on which I should like information is the question of steam pressures. Have they been worked out from an economical standpoint? So far as my own investigations go I cannot see any economical justification for exceeding a figure of about 400 lb. per sq. in. under our conditions. With regard to hot-water heating, from the author's remarks with reference to condensing during the summer months I presume that during this period the hot-water heating is cut off entirely. Can the author say what is the overall efficiency of the station under hot-water heating conditions?

Mr. R. M. Charley: The only picture of a transformer substation which the author has exhibited on the screen shows a forced oil-cooled transformer. Perhaps the climate necessitates the cooling equipment of the transformers being located indoors. It would be interesting to know whether transformers of the naturally-cooled type with or without the addition of air-blast cooling—which are now so popular in this country—have been successfully used in the more severe climatic conditions of Russia.

Mr. T. G. P. Nettleship (*communicated*): I should be pleased if the author could give me an idea of the output of, and number of workers employed in, the telephone factories mentioned in Table 17. Also, I should be interested to know what system of automatic telephony has been adopted in Russia, and how the problems of long-distance communication are being overcome.

The Author's Reply to the Discussions at London, Liverpool, Manchester, Nottingham, Leeds, Edinburgh, and Birmingham.

Mr. A. Monkhouse (*in reply*):

Preparation of the Electrification Plan.

Numerous speakers have asked whether the plan for the electrification of Russia was worked out by Russian engineers or whether foreign assistance and advice were obtained. The main details were drawn up by the G.O.E.L.R.O. commission—a group of Russian engineers, the majority of whom had pre-war training—without assistance from abroad. It was only when it became necessary to order equipment and enter into detail with regard to its arrangement in the power stations that foreign contractors were invited to render technical assistance. Foreign firms of consulting engineers have not, as a general rule, been employed, except in the case of the larger hydro-electric installations.

Finance.

Mr. Engblom and others ask as to the source of the money with which the Soviet Government have purchased electrical equipment from abroad, and also how the money is raised within the U.S.S.R. for the work done in that country. The Government have been unable to raise any foreign loans. The only assistance of this kind they have been able to get has been in the form of credits given to them by manufacturers accepting long-term bills. These credits have, as a general rule, been insured or backed by some guarantee given by the Government of the manufacturers' own country. Credits of this kind have been for periods varying from 12 to approximately 36 months, although in individual cases payments extending over longer periods have been arranged.

The Soviet Government have met the bills on presentation with extraordinary punctuality. They make their payments from the money which comes to them from the sale of timber, wheat, oil, flax, agricultural produce, etc., a large part of which is sold to Great Britain. In the years 1931 and 1932 they had to augment their budgeted exports by the additional export of certain manufactured articles, including textiles, lamps, sweets, etc., because the general slump in world prices had threatened them with being in the position of not having sufficient funds to meet their bills. Normally, however, their rapidly growing home demand will not make the export of manufactured goods possible as a general rule, and, moreover, their exports of wheat and oil will probably be curtailed as internal demand increases.

In order to meet their demands for money with which to pay wages and purchase materials of Russian origin, the Government have raised numerous State loans to which all Soviet workers are encouraged to subscribe. These State loans are practically the sole opportunity which a citizen of the U.S.S.R. has for investment, apart from depositing his money in the State Savings Bank or in other State banks. All banks pay good interest on both deposit and current accounts. The interest payable on the State loans is of the order of 7 to 8 per cent. The money raised by these loans is largely directed to the constructional work being done under the State Plan,

and most of the loans have been definitely raised for that purpose. Ordinary State expenditure—the army, education, public services, etc.—is met out of revenue derived by taxation. A steeply graduated income tax and a turnover tax on State industries are the Government's main sources of revenue.

Personnel.

Many speakers have inquired whence the Soviet authorities have drawn their personnel for building and operating their power stations, and also what technical education facilities exist in the U.S.S.R. to-day.

The shortage of trained technical personnel has been a very serious handicap in the carrying out of the Five-Year Plan as a whole—but it is a handicap which is now rapidly disappearing. In the early days the work was largely in the hands of men who had held responsible positions under the old Government. Contrary to popular conceptions, the technical intelligentsia of Russia was not decimated during the revolution, and relatively few of the men of this class left the country. When the electrification plan was put into execution in about 1923, these men entered wholeheartedly into the work. During the last 12 years the large technical schools and universities of Moscow, Leningrad, Kiev, Harkov, etc., have turned out many thousands of young men trained in the rudimentary theories of electrical engineering, and during a period of intensive development, such as that through which the U.S.S.R. has been passing, these men have had a unique opportunity for gaining experience and showing initiative. The result of this has been that many of the younger men have developed extraordinarily rapidly and assumed positions of responsibility which only come to men of very much more mature years in the older European countries.

With regard to skilled workmen, this has not been as serious a difficulty in the building and operation of power stations as might be generally thought, because during the constructional periods the main responsibility for skilled workmanship fell upon the erectors sent to the U.S.S.R. by foreign contractors; and, of course, once the stations are complete there is not a great deal of work about a power station which necessitates employing highly skilled workmen.

In the electrical manufacturing industry on the other hand the shortage of skilled operatives has been a serious factor; but in this case, as elsewhere, the policy of the Government has been to introduce, wherever possible, mass-production methods of manufacture using specially designed machine tools and eliminating highly skilled workmanship. In the heavier electrical industry, mass-production methods are out of the question, and only during the last few years have skilled men become available in anything approaching a sufficient number.

Mr. Brearley asks whether an apprenticeship scheme is in existence and how the Soviet authorities select men for training for higher posts.

The majority of the senior schools in the U.S.S.R. are closely associated with the local industrial establishments, and young people spend part time in the works and factories and part time in the schools. During this period the brighter pupils are singled out for sending to the technical schools and thence to the senior universities.

There was a time when men were allowed to enter the universities from the so-called workers' faculty schools (a form of continuation school), but the students thus admitted were seldom found to have had sufficient grounding to take full advantage of the university courses. Changes have recently been made and entrance to the universities is a matter of matriculation. There has also been a distinct tightening up of the educational standard required for men entering the universities, and also in the examination they have to pass in order to obtain their diploma on graduating.

Salaries and Rates of Payment.

Various speakers have made reference to popular misconceptions with regard to the rates and scales of payment to be found in the U.S.S.R. to-day. Throughout the electrical industry, as elsewhere, the rates and scales of payment are graduated in almost exactly the same proportions as those that exist in Great Britain. The Soviet authorities have long ago realized the necessity of payment of wages and salaries according to results and to services rendered. Piece-work is adopted universally in the manufacturing industries.

Cost per kW Installed of Stations in U.S.S.R.

The rapid changes which have taken place in the U.S.S.R. during recent years, involving also considerable changes in the purchasing power of the rouble, have made it very difficult to give reliable comparative figures as to the cost of stations per kW installed. At the present time the figures for large stations may be taken as:—

Peat-burning stations .	320–360 roubles per kW
Pulverized-coal stations .	280–310 roubles per kW
Thermal-electric stations .	500–550 roubles per kW
Hydro-electric stations .	600–700 roubles per kW

According to the nominal rate of exchange existing between the rouble and the £ these figures would appear very high. It has been pointed out in the paper, however, that the nominal rate of exchange cannot be accepted as representing the real rate, and that the purchasing power of the rouble in the U.S.S.R. is equivalent to approximately 6d. in Great Britain. Under such conditions the above costs per kW are low compared with British practice.

Distribution of Load of Glavenergo Stations.

I have been asked how the load on the main stations is made up. The figures in Table A apply to the Moscow District system (Mosenergo).

TABLE A.

Distribution of Load of Moscow Power Authorities' Network.

	Traction	Lighting	Industrial
	million kWh	million kWh	million kWh
1928	410	154	110
1929	565	185	125
1930	729	255	153
1931	1 050	295	166
1932	1 379	371	204
1933	1 640	460	235

From this it will be seen that the domestic and lighting load occupies a relatively small place in the total output of the Moscow stations. Moscow has not many heavy industries; consequently, the industrial load is also not large. These figures must not be assumed to apply in the same proportion in other parts of the Union, because with the exception of Leningrad, Harkov, and Baku, the traction load on the power stations is very small. The above table is, however, indicative of the position in the larger cities. The total distributed output of the Moscow stations in 1933 was 2 679·5 million units. As the total installed capacity of the power stations in the network was 577 000 kW, it is clear that the Moscow authorities anyhow cannot encourage the use of electricity in the home until their generating capacity has been increased. In actual fact, in the winter of 1932–33 they were actually discouraging the use of electricity in the home and limiting its use by imposing heavy rates for all units used in excess of what was considered by the municipality to be a fair lighting load.

Mr. Haldane asks what is meant by the words "average installed generating capacity" in Table 2. His assumption is correct when he says "Possibly it is the average for the year, where a station is being rapidly extended." He also asks if the Donsoda power station is not to be connected to the Harkov network. I think that it is, probably through the Eshar power station, but this connection was not shown on the map in Fig. 2 because I have no definite knowledge of its existence.

Domestic Electrical Load.

It has been pointed out that no mention is made in the paper of domestic electrical load. Under the circumstances outlined above it will be clear that domestic loading is not encouraged at present. The Soviet authorities, however, are not blind to the advantages of the "all electric" house, and provision is being made for this in their new cities. Definite plans exist for domestic-equipment factories which will commence work as soon as the power-supply shortage permits.

Rural Electrification.

Mr. Bramwell and others inquire as to what progress is being made with rural electrification. A certain amount of work has been done. The collective farmers and those in charge of the State farms naturally wish to avail themselves of electrical energy, since the propaganda authorities have consistently explained to the people that in electrification they have the solution of many of their difficulties. The Central Power authorities, however, are not yet in a position to distribute large amounts of power in the agricultural districts, and hence it is not uncommon to find small sets being put down by local agricultural bodies. In this connection quite an appreciable quantity of power produced by small generating units driven from tractors is now being supplied to villages. Sixty-eight such stations exist which in 1933 had a total generating capacity of 3 137 kW.

Table B gives the actual figures for the amount of generating capacity devoted to rural electrification.

As an example of how electric power is used on the collective farms the figures in Table C, taken from a machine-tractor station in the North Caucasus area, may be of interest. These State-owned machine-tractor stations are actually small engineering service stations serving groups of collective farms and providing facilities for threshing, grinding, crushing, etc., and also in many cases for making butter.

TABLE B.

	1929	1933
	kW	kW
Power from main Glavenergo transmission lines through substations	598	12 846
Local hydro-electric stations ..	7 094	8 795
Local steam stations	6 466	8 178
Local Diesel stations	8 904	25 534
Local tractor-driven stations ..	30	3 137
Local oil-engine (other than Diesel) stations	5 588	7 279
Local producer-gas engine stations	911	1 085
Total	29 591	66 854

TABLE C.

Electrical Equipment. Limansk Machine-Tractor Station. (North Caucasus.)

	No. of motors	Total h.p.
Threshing machines	6	100
Irrigation of vegetable growing area ..	3	50
Grinding mills	2	36
Butter making churns	1	7·5
Separators	4	4
Winnowing machines	2	1·5
Potato sorting-machines	2	1·0
Indian corn crushing-machines	5	26·5
Hay and ensilage cutters	4	37·5
Sorghum crushers	1	7·5
Repair workshops	5	7·75

Fuels.

Mr. Abell asks as to the fuels which the Russians use in their stations. Table D shows more clearly than

TABLE D.

Fuel	Million kWh generated	Percentage of total generated power
Oil	1 437·2	18·5
Donetz coal	2 447·2	31·5
Moscow brown coal	651·0	8·4
Ural and Siberian coal	411·8	5·3
Peat	1 639·5	21·1
Wood	183·1	2·3
Waste products	376·2	4·8
Hydro-electric	632·0	8·1
Total	7 778·0	100

Table 2 of the paper the relative importance of the various fuels. The figures are in relation to the main stations of Glavenergo during the year 1932.

The wood fuel about which the question was asked was used at the Ivanovo-Vosnesensk station and at Krasni-October in Leningrad to make up shortages in the supply of peat which occurred in 1932 as a result of a very poor peat harvest. The failure of the peat campaign in 1932 was chiefly due to weak organization and a failure of the peat-winning authorities to maintain pace with power-station development.

Peat Fuel.

The section of the paper dealing with peat fuel has interested several speakers. Since the paper was written, work on this important development has been proceeding along the lines foreshadowed. A fuel conference recently called in Moscow pressed for extending the use of milled peat, and apparently the Shershnev type of grate has proved sufficiently satisfactory to warrant a recommendation being adopted for its general use.

For igniting the fuel in grates of this kind oil burners are fitted, and in many cases it has been found advantageous to supply the furnaces with a certain amount of oil fuel to assist combustion of the peat when the latter has an excessively high moisture content. In this manner peat fuel containing as much as 62 per cent moisture has been burned. With reasonably dry peat, however, the oil is cut off as soon as the correct furnace temperature has been reached.

The question of the ash from peat has interested many speakers. The peat-burning stations are almost all situated in open country in the vicinity of the bogs, and therefore if ash were distributed from the smoke stacks it would not be a serious matter. In fact, ash disposal has not been a serious difficulty at these stations. The ash contents of Russian peats are low, varying from 4 to 6·5 per cent on the average.

It is not easy to show the relative costs of peat and coal in Russian stations, because all the main peat stations are situated on the bogs and have no heavy transport charges for their fuel. The following figures indicate what are regarded as the present relative costs per metric ton of fuel at the bunkers in the largest Glavenergo stations:—

Peat	29·50–30·75 roubles.
Pulverized brown coal ..	25·60–27·50 roubles.
Pulverized anthracite spoil ..	12·05–12·75 roubles.

In reply to Prof. Teago's question as to the possibility of working the peat on the northern tundras of the U.S.S.R., I would point out that the "milled peat" method of winning this fuel will permit the northern bogs to be worked throughout the summer.

Burning of Lignite Coal.

Mr. Kerr asks whether the Russian power stations have received much information from German practice in dealing with the problem of burning lignite coal. I think it would be fair to say that the great progress which has been made in this connection, particularly at the Kashira power station of the Moscow power authority, has been based on information and advice received from Great Britain and France rather than from Germany. It must be borne in mind that this and the very large station recently completed at Bobriki work with pulverized fuel.

At Kashira power station a very great deal of most interesting large-scale experimental work has been done, with the object of determining the most satisfactory method of pulverizing brown coal and burning it as pulverized fuel. This work has been fully reported in the Russian technical Press.

Anthracite from Spoil Banks.

Mr. Longman and others ask what degree of success the Soviet engineers have met with in the burning of anthracite spoil. There are now six large stations burning pulverized anthracite spoil, and the operating results of the boiler houses of these stations have recently been published in the Russian technical Press. The Soviet engineers have come to certain definite conclusions regarding the design of both burners and combustion chambers for this type of fuel, and these are being incorporated into the extensions of the existing stations. They favour the use of well-type combustion chambers without any hanging upper-arches. The combustion chambers are to be completely water-screened. Rectangular slot-type burners are to be used. The air for the furnaces is to be preheated to 375°–400° C.

Operation of Overhead Lines.

Many speakers have asked what difficulties, if any, the Russian authorities have encountered in the operation of their overhead lines, pointing out that their allowances for ice formation and wind are actually less stringent than those laid down in Great Britain.

This is not surprising, because as a general rule the extreme cold of the Russian winter results in a dry atmosphere, and consequently bad ice conditions do not occur except possibly for a week or two in the autumn and in the early spring. Winds of gale force such as have to be provided for in Great Britain seldom occur in Russia except in the case of very rare tornado-like whirlwinds accompanying thunderstorms during the summer.

The worst ice conditions occur on the steppes of the Ukraine. In this district the operating authorities endeavour to prevent ice forming on the wires and remove it, if formed, by "pumping" wattless current through the lines. This is an exciting task for the engine-room staff because, as the ice detaches itself from the wires, the latter bounce upwards and frequently make contact with the wires of an adjacent phase. I have seen "shorts" of this kind coming on at intervals of less than a minute. The wonder was that the generating and transformer plant withstood the stresses thus imposed.

Lightning and atmospheric discharges during the hot summer season are responsible for a considerable number of the failures on the transmission systems of central Russia. As a general rule no lightning protection has been provided on the 110–115-kV systems, and the neutral points of the e.h.t. windings of the transformers have been solidly earthed. The number of line failures per 100 km of line has definitely increased during recent years, despite the fact that care has been taken to grade the insulation on the systems. The figures in Table E refer to the Moscow network.

The figure of 3 failures per 100 km of line which occurred in 1932 has caused the Moscow authorities to

view with disfavour the practice of earthing the neutral points of e.h.t. transformers, and in future work unearthed neutrals will probably be specified for 110–115-kV lines. It is realized, however, that on the 220-kV lines earthed neutral points will doubtless be necessary.

The existing networks of the system are to be protected as far as possible by using graded insulation. It is intended that all open-air substations should be protected from direct lightning stroke by lightning conductors placed at their four corners. The overhead lines to substations are to be provided with an earthed guard-wire for 2 km on either side of through substations, and 4 km when approaching terminal substations. At the points where the guard wire is discontinued tubular expulsion-type lightning arrestors are being fitted.

It is realized that the tubular expulsion-type arrestor has drawbacks, but as a temporary and inexpensive measure it is being generally adopted. It is intended that some of the more important points in the network should be protected with larger lightning protection equipment of the types in general use abroad.

Expulsion-type arrestors are also being extensively used on the 30-kV and the 6 000-volt lines. They are being made in the U.S.S.R. but, owing to the difficulty

TABLE E.

Year	Number of line failures	Number of failures per 100 km of line in network
1928	4	1·23
1929	9	1·86
1930	19	2·63
1931	19	2·52
1932	30	3·00

of obtaining strong fibre tubes, bakelite tubes lined inside with fibre are being used.

Several speakers have referred to the design of the wooden poles which the Soviet engineers have adopted. This construction is the result of very extensive field tests. In reply to Mr. Fennell I would point out the bottom sections of the poles are not made of concrete but of timber. Occasionally, old railway lines are used and the pole is spliced between them. The spliced pole is used in order to enable the lower part to be replaced without interruption to the working of the line. Grass fires, parasites, and rotting of the timber, render this provision necessary.

Railway Electrification.

Mr. McKinnon and Dr. Sims ask whether the Murman Railway and other lines in the extreme north of European Russia are to be electrified.

The Murman Railway is the one link the U.S.S.R. has with the Atlantic during the winter months when the Baltic Sea becomes frozen, and thus it is a line of considerable seasonal importance. It is over 800 miles in length, and no local fuel except wood and peat is available. Water power is, however, plentiful, and hence it appears to be rational to electrify this line. The Soviet authorities have therefore included the Murman Railway amongst those which will be electrified in the near future. The development of the extensive apatite deposits on the Kola peninsula have also given importance to the line.

Other speakers are interested in the Suram Pass (Transcaucasian Railway) and the Lunevski line (Urals) electrification work, on account of the fact that these lines were electrified in order to solve electric braking difficulties. On the Suram Pass the maximum gradient is 29 in 1 000 and the total length of the down grade is about 30 miles.

In reply to Mr. Brierley's question, the railway gauge throughout Russia is now standardized at 5 ft. The loading gauge is extremely large; this has been a convenience in moving heavy plant about the country. Turbo-alternator stators, condenser shells, and parts of large rolling-mill motors, which could not be dealt with on the British railways, were transported by rail without difficulty in the U.S.S.R.

Prof. Say asks why the Siberian Railway has been included in the electrification plan. He assumes that the traffic on this line is not heavy. On the contrary it is very heavy indeed, and as the new industrial districts —the Urals and the Kusnetzsk Basin—develop, this traffic will assume such large proportions that the electrification of this section will not be sufficient and the line will need paralleling. The work of building a double-track parallel line is already in hand.

Raw Materials Supply.

Mr. Swale asks whether the new industries of the U.S.S.R. are independent of supplies of raw materials from abroad. At the moment considerable quantities of constructional materials, including sheet steel for core building, rotor forgings, turbine discs and blading, high-pressure boiler drums, electrical insulating materials, tungsten, etc., are imported, but it is not out of the question to expect that in a few years' time the only materials which the Russian electrical factories will find themselves compelled to import will be tin, rubber, and shellac. These three products have not been found in the U.S.S.R. In other words the U.S.S.R. is very similarly placed to the U.S.A. with regard to its natural supplies of raw materials.

Overloaded Power Stations.

Mr. Goodlet stresses a very pertinent point when he speaks of the overloaded condition of the Moscow power stations—particularly 1st Moscow power station which is supposed to function as a peak-load station. Under such conditions the plant installed does not receive the attention it would under more normal circumstances. However, this station has run extraordinarily well and the published results reflect credit on those responsible.

Distribution Voltages.

The question of what distribution voltages have been standardized has interested several speakers. In the majority of cases 6 600 and 3 300 volts are used for distribution from the secondary substations to the local distribution substations. The voltages brought into consumers' premises are 220 volts (phase voltage), corresponding to 380 volts between phases. The lighting voltage is therefore 220 volts almost everywhere. During recent years the overloaded condition of the networks has frequently resulted in voltages dropping to 200 on systems normally rated at 220 volts.

Metering to Consumers.

Several speakers have asked whether electricity is metered out to consumers. The answer is that it is metered out in a manner very similar to that in vogue in other countries. Meters are installed in every dwelling-house or flat, and charges are made in the usual way. Prepayment meters are not used.

The meters are now all of Russian manufacture. Mr. Whitehead asks whether the Russian meter factories can cope with the demand for their product. It is true that they are working at full output to meet this demand, and their output is of the order of 2 000 meters per day.

Telephones.

The development of the telephone services in the U.S.S.R. and the source of the equipment being employed have interested various speakers.

The telephone services in Soviet Russia are being rapidly improved. The larger cities are being converted to automatic working, and the long-distance services are being extended. The telephone service between Moscow and Kuznetsk (Russian Mongolia), for instance, involves speaking over some 2 500 miles of overhead line. From a technical point of view this line works well. The drawback against relying on its use is the fact that it is very heavily loaded with official calls, and hence delays of two or three hours may occur in making connection.

The equipment for these improved telephone services is all being made in the Krasni Zoria telephone works in Leningrad, and Moscow telephone works. These works are well organized and have been equipped with modern mass-production machinery. Experience has shown that their product is good and reliable and its finish is better than that of most of the products of Russian factories to-day. The tendency in Soviet factories as a whole to-day is to concentrate on ensuring that essential working details are sound, rather than to devote time and attention to finish.

Standardization and Specifications.

Mr. Welbourn and Mr. Waygood ask for further details of the specification for paper-insulated cables, to which reference is made in the paper. This specification is now, I believe, available in the English language through the Cable Research Association.

Specifications for transformers and other electrical plant are now appearing, and these, like the cable specifications, are very complete indeed.

Mr. Brearley asks " Does the U.S.S.R. co-operate in the formulation of international technical standards?" The answer is that it does. Russian representatives attend the conferences of the International Electrotechnical Commission.

Mr. Siviour asks whether the Soviet authorities intend to fall in with international standardization recommendations. As a general rule they have done so wherever possible, but still the Russians hold themselves free to depart from international standards wherever they feel that, on account of their special conditions and the youth of their industries, this is desirable.

Excavators.

Mr. Rushworth asks whether excavators are in general use in the U.S.S.R. for canal-cutting and similar work. A certain number of large excavators have been imported and used, but much of this class of work is still done by employing the mass labouring system. Sluicing with high-pressure water is also used for excavation work.

Short-Circuit Testing Plant.

In reply to Mr. Gurney, I would confirm that the short-circuit testing plant in Moscow will have an instantaneous rating of the order of $1\frac{1}{2}$ million kW.

High-Tension Direct-Current Transmission.

Mr. Charley refers to the proposal, which the Soviet engineers have been investigating, that they should utilize high-tension direct current to solve their long-distance transmission problems. Investigational work is still in progress and it is possible that an experimental line may shortly be put into operation. This work has recently been described in the Russian technical Press.

Concrete Work in Winter.

Mr. Jeffrey wonders how the Soviet authorities manage to erect concrete buildings in their hard winter climate. Wherever possible, concrete work is done during the warmer months of the year, but if it is essential to run concrete in the winter a temporary wooden housing is built over the whole job. The Volhov dam, for instance, was completed in the winter time under an immense wooden shed in which the temperature was maintained about 0° C. by steam-heating and wood fires in braziers. Large buildings are frequently completed in the same manner.

Coiled-Coil Lamps.

It is true that the Russian lamp-works have been manufacturing coiled-coil lamps since 1932.

Technical Assistance in Manufacturing.

I would point out to Mr. Colvin-Smith that the Russian electrical factories have had technical-assistance agreements with German, American, and British manufacturers. Under these agreements they have purchased designs and, in some cases, secured the assistance of foreign specialists. Where it has not been possible to get technical assistance from foreign firms they have invited individual foreign specialists to come to their assistance. Naturally they get some information in the manner Mr. Colvin-Smith suggests.

Cost Accounting.

In reply to Dr. Garrard, both in power-supply work and in electrical manufacturing, costs are taken out in the same manner as in other countries, except that no allowance is made for interest on capital. Depreciation is allowed for and other overhead charges calculated in the usual manner. The accounts of all works and State institutions are subject to audit by the Workmen's and Peasants' Inspection Commissariat of the Government. This is, in fact, a State audit department.

Transformer Cooling Arrangements.

In reply to Mr. Charley, the earlier power plants were built with forced oil cooling for outdoor transformers. In this case the cooling equipment was housed in special buildings. Recently, however, naturally-cooled trans-

formers have been installed in many parts of the country and operate satisfactorily even under the extreme winter conditions.

Research.

The attention which has been devoted to research work in the paper itself is rather meagre in view of the immense amount of important research work now being carried on in the Soviet Union. Many speakers have asked whether the results of these investigations will be made known to the outside world. The answer to that question is definitely in the affirmative. Up to the present the new research institutes have been establishing themselves, training personnel, and covering preliminary ground. They have had a very definite tendency to copy and repeat research work which they learn is in progress in other parts of the world, but in doing so they frequently open up new aspects of the problems involved. In many cases they are able to conduct their researches on a wider scale than those they set out to follow, because they have behind them a Government willing and able to expend almost unlimited funds on development work. The cryogenic laboratories in Moscow and Harkov may be mentioned as examples illustrating this point. It would not be fair, however, to give the impression that Soviet research is not covering some original ground. Original research work is going on and the results of some of this work are now being made known.

Mr. Brierley asks whether research is organized on an institutional or a competitive basis. The whole of the industrial research for the heavy industries is grouped under one deputy commissar in the person of Mr. Bukharin. His department controls the various research departments of the different heavy industries and is supposed to co-ordinate their work so as to avoid overlapping. Likewise, in each section of the heavy industries a similar arrangement exists. Central laboratories have been set up for dealing with fundamental research problems of common interest to the section in question, and these laboratories work in close co-operation with the application and materials control laboratories in the individual works. The academic bodies such as the Politechnical Institute of Leningrad, the Institute of Metals, and the Thermo-technical Institute, are also engaged on research work, and channels exist to ensure that these bodies supplement the work of the central laboratories. In general the academic laboratories are entrusted with work of national importance, for instance super-high-tension distribution over long distances, fundamental physical research work, fuel research, etc.

Russian Technical Literature.

The Soviet authorities definitely do not intend to maintain a policy of secrecy with regard to their fundamental and industrial research activities, and hence, now that results are beginning to come from their vast research organizations, the Russian technical Press is becoming monthly more and more valuable. In the electrical industry the technical Press is concentrated under one authority and hence there is no overlapping in its contents. A series of 16 papers are issued under the following names.

Technical:—

News of Weak-Current Electrical Industry.
Electrichestvo.
Electric Power Stations.
News of the All Union Thermo-technical Institute.
Diesel Building.
Heat and Power.
Hydro-Electric Construction.
News of the Heavy Electrical Industry.
Energy Review (abstracts of world's technical Press, etc.) Electrical.
Energy Review (abstracts of world's technical Press, etc.) Thermo-technical.
Soviet Boiler Construction.
Electric Traction.
Light (illumination) Technics.

Popular:—

The Stokers' News.
Electrification and the Electrician.
The Engine Man.

In addition to these the technical institutes and various research organizations make a practice of publishing their reports at regular intervals.

There is no doubt whatever that the technical literature of Russia will shortly take an important place in the world's technical literature, and young engineers in Great Britain who go to the trouble of learning the somewhat difficult Russian language will undoubtedly find their efforts worth the time and money expended.

Mr. Volin has been good enough to make certain additions to the figures shown in the original paper, and refers to some of the large steam boilers now being built in the U.S.S.R. I should like to thank him very much for his remarks. His concluding statement provides an explanation of how it has come about that the Soviet Government has succeeded in achieving so much in a relatively short period. I do think, however, that it is necessary to point out that in reviewing the electrical progress in his country we are examining a development which has had the concentrated attention of the Government over a period of 14 years and has thus achieved more than most of the other sections of industry which have only been intensively developed since 1928.

In conclusion I should like to thank several speakers for pointing out two errors which occurred in the advance copies of the paper and which have been corrected for the *Journal*.

CONDUCTION THROUGH TRANSFORMER OIL AT HIGH FIELD STRENGTHS.*

By J. F. Gillies, B.E., B.Sc.(Eng.), Ph.D., Associate Member.

(*Paper first received 22nd May, and in final form 3rd September, 1934.*)

Summary.

Experiments have been carried out to investigate the conductivity and power factor of transformer oil at high stresses. It has been found that the relation between the applied voltage (V) and the conduction current (I) under direct stresses between 50 and 300 volts per mil can be expressed by the equation $I = kV^m$, where m is approximately 3. At stresses between 50 and 120 volts per mil, the relation may be expressed more accurately by the equation $V = V_0 + nI$. The specific resistance of pure transformer oil at a stress of 50 volts per mil is greater than 4×10^9 megohms per cm cube. The power factor of pure transformer oil is of the order of 0·00005 at stresses under 70 volts per mil (r.m.s.), but above this stress it increases rapidly. It is suggested that the observed results can be explained by a theory of ionization by collision at high stresses.

Introduction.

While a considerable amount of investigation has been carried out on the characteristics and nature of the conduction of electricity through solid dielectrics, less attention has been given to the corresponding problems in regard to liquids. The work which has been done previously on liquids has been confined largely to low stresses. Measurements have therefore been made of the conductivity of transformer oils at direct stresses from 20 to 300 volts per mil and of the power factor under alternating stresses from 10 to 100 volts per mil.

"Gargoyle" transformer oil, conforming to the British Standard Specification (No. 148—1933) for a Class A30 oil, was used. The tests were carried out at a temperature of 18° C., at which temperature the specific gravity of the oil was 0·86 and the viscosity 160 Redwood seconds. Before test, the oil was dehydrated by agitation over calcium turnings.

Previous Work.

Nikuradse† gives a very complete résumé of earlier work carried out at low stresses by such workers as von Schweidler, Kohlrausch, Warburg, Jaffé, and others, as well as of more recent work in the same region of stress. It appears from their results that in a wide variety of liquid dielectrics such as hexane, toluene, carbon bisulphide, carbon tetrachloride, and various slightly impure liquids, a saturation current is observed when the stress exceeds a certain limit. With pure hexane the saturation current is observed at stresses of from 1 to 3 volts per mil, and similar values of stress hold for other liquids.† Measurements carried out with the help of small exploring electrodes, and also by observation of the Kerr effect for light passing through the central region between the electrodes, have shown definitely the existence of space charges at the electrodes at stresses less than that necessary to produce saturation. Nikuradse‡ has observed that in some cases the space charges disappear after the stress has been applied for some time, while an increase of stress may also cause them to disappear. These results are probably obtained from measurements made in or near the saturation region, where the decrease of the current to the saturation value is accompanied by the production of a uniform field between the electrodes.

At these low intensities, Nikuradse found that the conductivity of the oil may be reduced by heating the electrodes to a red heat and thus degassing them before use; this result indicates that gaseous ions may be removed from the electrodes and carried into the oil by the action of the current. Polarization effects were also observed whereby, if point and plate electrodes are used, a greater current is observed for the same voltage when the point is negative than when it is positive.

Black and Nisbet§ describe a series of experiments on a highly purified medicinal paraffin from which it was found that between stresses of 1·5 and 0·03 volts per mil the voltage and current were connected by a law of the form

$$V = R_0 I + nI^2$$

though in some cases from 5 to 6 hours elapsed before a stable value of the current was obtained. With thin films of oil, the current decreased more rapidly to the stable value, but a saturation current was indicated at a stress of 43 volts per mil. Though there was no residual discharge current, there was evidence that, after stressing, the resistance of the oil remained at a higher value for some time.

Experiments by Welo‖ on the direct-current conductivity of transformer oil and also of dimethyl octane and normal decane, again show the presence of a saturation current at a stress of about 20 volts per mil. It was found that successive distillations of the oil *in vacuo* reduced the conductivity to a value of the order of 10^{18} mhos per cm cube.

Nikuradse¶ describes work carried out on transformer oils at stresses up to 80 volts per mil, in which region the current ceases to have the saturation value and begins

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† See Bibliography, (1).

† See Bibliography, (2). ‡ *Ibid.*, (3). § *Ibid.*, (4). ‖ *Ibid.*, (5). ¶ *Ibid.*, (6).

to increase rapidly with increase of voltage. In some cases he found that the current and voltage were connected by the relation

$$I = I_0 e^{kV}$$

If δ is the distance between the electrodes and ϵ the field strength, the relation takes the form

$$I = I_0 e^{k\delta\epsilon}$$

or, if the field strength is constant,

$$I = I_0 e^{m\delta}$$

and such a law was found to apply when the spacing between the electrodes was altered keeping the field strength constant.

Race,* on the other hand, finds a law of a different form to be true in the same region of stress. From experiments on a heavy cable oil the law

$$\gamma = \gamma_0 e^{\alpha T} e^{\beta g}$$

was found to connect the conductivity (γ) with the voltage gradient (g), T being the absolute temperature, while γ_0, α, and β, are constants. If the temperature is constant, the relation between the voltage and current derived from the preceding equation takes the form

$$I = aVe^{bV}$$

a and b being constants. This equation differs from the form found by Nikuradse.

The power factor of a pure transformer oil is very low. Welo† gives the value at a stress of 75 volts (r.m.s.) per mil as 0·0004 at a temperature of 20° C., rising to 0·0046 at 135° C. The presence of moisture causes a considerable increase in the power factor, as is shown by the results of Shrader,‡ who observed a power factor of 0·005 at a stress of 35 volts per mil with a transformer oil containing 0·002 per cent of moisture.

The presence of polar molecules in an oil causes a considerable modification of the electrical characteristics, but as transformer oils are non-polar no reference has been made to observations on polar oils.

Experimental Methods.

The high-voltage supply for the following experiments was obtained from a 440/80 000-volt step-up transformer controlled on the primary side by an induction regulator and tapped auto-transformer. For the direct-current measurements, the output was rectified by a 40 000-volt rectifying valve. The voltage across the sample was measured by a high-tension electrostatic voltmeter, while the current through it was obtained from a galvanometer of the Broca type having a sensitivity of 20 000 mm per microampere. The complete circuit for the direct-current measurements is shown in Fig. 1.

The power-factor measurements were carried out using a Schering bridge, the current in the galvanometer circuit being amplified by a 2-stage thermionic amplifier. The bridge, the complete circuit of which is indicated in Fig. 2, was completely screened and a Wagner earthing system was used to compensate for the earth capacitances, this being essential in the measurement of low power factors.

Two types of vessels were used to contain the oil under test. The first type, which is shown in Fig. 3, is con-

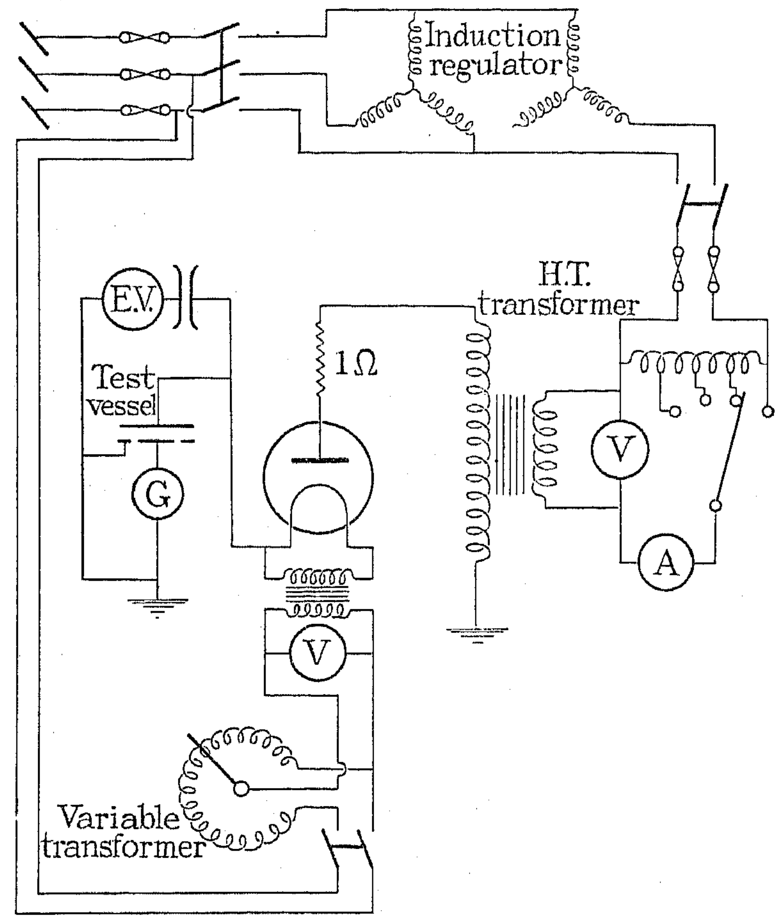

Fig. 1.

structed of sheet tin and thus acts as a shield to screen the electrodes. The latter are brass discs, 2 in. diameter, with the edges rounded to prevent excessive electrical stress round their peripheries. The low-tension electrode

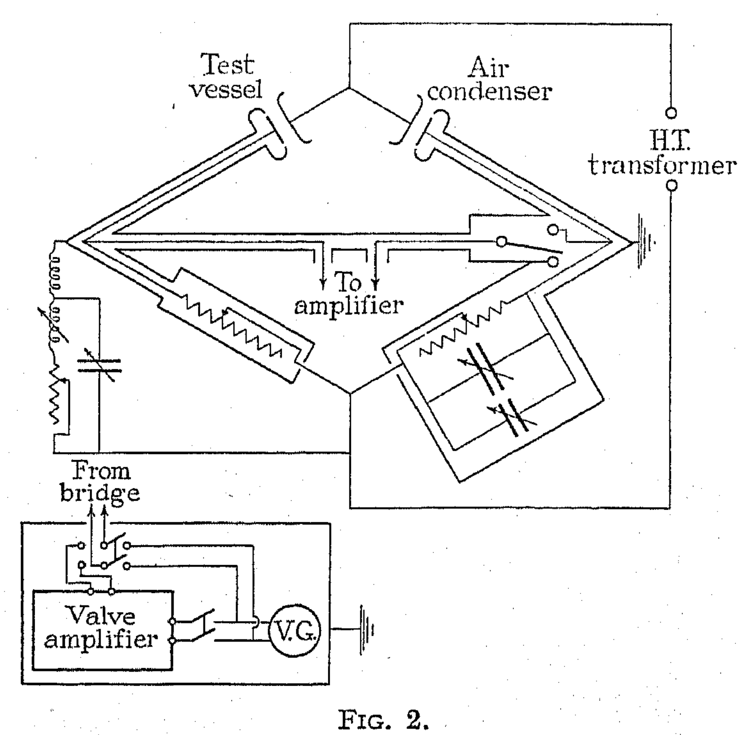

Fig. 2.

is supported by a rod passing through the side of the vessel but insulated from it by an ebonite bush, while the high-tension electrode is supported from an ebonite framework mounted on top of the vessel as indicated. A

* See Bibliography, (7). † *Ibid.*, (5). ‡ *Ibid.*, (8).

lid, from which the high-tension electrode is insulated by a rubber bush, slips over the top of the vessel and completes the screening when it is used for alternating-current measurements.

The capacity of this vessel is about 700 cm^3, and for later experiments the container shown in Fig. 4 was constructed, with the object of enclosing a greater proportion of the oil in the space between the electrodes.

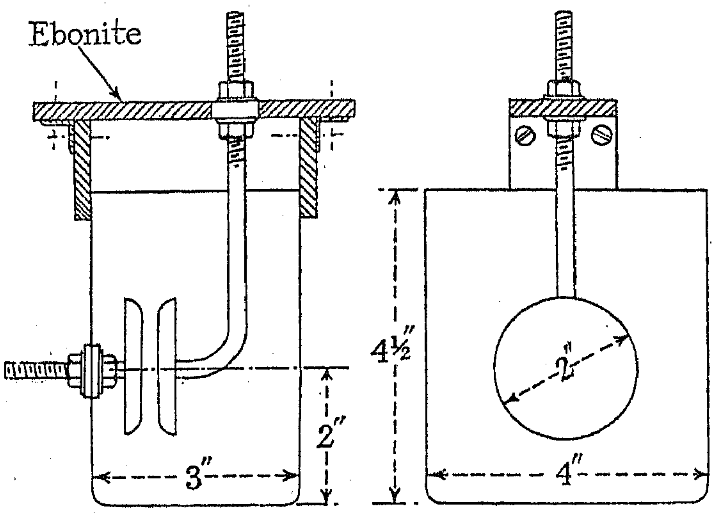

FIG. 3.

The high-tension electrode is supported by a plate of ebonite, while the low-tension electrode is supported by a brass plate from which it is insulated by an ebonite bush. The two plates are separated by U-shaped pieces of ebonite so as to form a vessel containing the electrodes, with only a small clearance between the electrodes and the sides. The electrodes are of the same dimensions and form as in the first container, and their spacing can be varied by inserting brass washers between the high-tension electrode and the ebonite wall. The brass plate forming one side of the vessel acts as a guard which

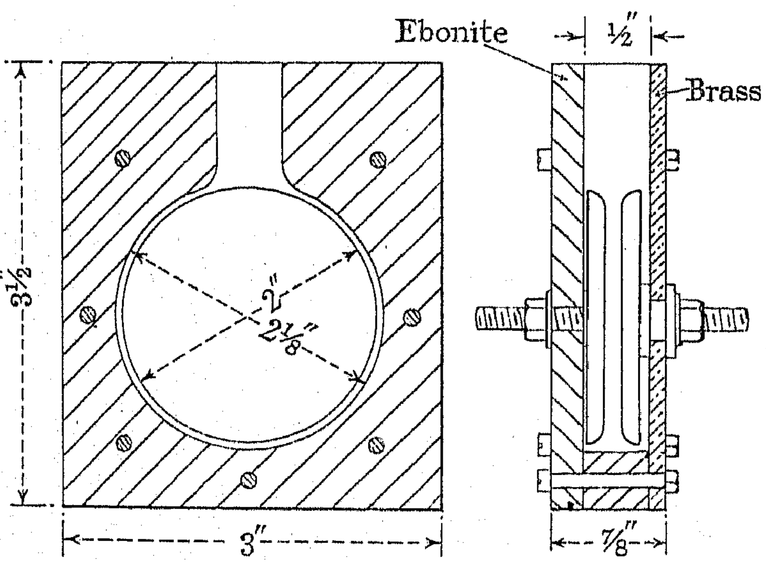

FIG. 4.

ensures that currents leaking along the surface of the oil or across the surface of the ebonite are conveyed to earth and do not enter the low-tension lead. To complete the screening, the whole vessel is enclosed in an outer zinc case from which the high-tension electrode is insulated by a rubber bush.

No guard ring was provided to equalize the stress round the edge of the electrodes, but the arrangement in both cases was such as to ensure that only the current actually passing through the oil under test passed through the galvanometer. Tests on the empty vessels at voltages approaching the breakdown voltage between the electrodes produced no current indication by the galvanometer, while the power factor of the empty vessels when measured under similar conditions of alternating stress was negligible.

Treatment of the Oil.

The oil used in these experiments was a Class A30 transformer oil supplied specially for the purpose, but preliminary experiments indicated the necessity for complete dehydration of the oil before it was tested. It was decided to carry out the dehydration by agitating the oil over calcium or sodium metal, since the bubbles of hydrogen released during the process serve as an indication when the action is complete. Calcium in the form of clean turnings was finally used, as being more easily manipulated for cleaning large volumes of oil, while the slowness of the action compared with that of sodium is compensated for by the larger surface area of metal offered to the oil by the turnings. The action was greatly accelerated by heating the oil to 80° C., and no deleterious effect was noticed in the oil after it had been held for some time at this temperature. As it appeared that the final traces of moisture could be removed only by prolonged exposure of the oil to the action of the calcium, each sample of oil was left in contact with the calcium until no further bubbles were observed to rise from the oil after it had been left undisturbed for 24 hours. Ten to fourteen days were found to be necessary for the complete dehydration of the oil, which was frequently agitated during this time. The oil was kept in contact with the calcium until it was required for test, and was then filtered directly into the test vessel. To ensure that no moisture was collected during filtration, the filter papers were heated in an oven to a temperature of over 100° C. for several hours and were then stored in a desiccator over fused calcium chloride until required. For the first series of experiments 800 cm^3 of oil were dehydrated at once, while for the later experiments, for which only a small quantity of oil was required, the process was carried out in 100-cm^3 flasks.

Cleaning of Test Vessels.

In view of the care taken in dehydrating the oil, equal care was necessary in cleaning and drying the test vessels before use. Before each test, the test vessel was dismantled and each part washed in pure carbon tetrachloride. After being reassembled, the vessel was rinsed out with three changes of fresh carbon tetrachloride, after which it was finally dried by blowing a current of hot air through it.

Accuracy of Results.

The galvanometer used for the direct-current measurements was calibrated before and after each test, and the calibration was found to remain constant. The voltage measurements were carried out with an electrostatic voltmeter of the Abraham type. As it was found possible

to reproduce the points on successive tests on the same sample, it may be taken that the limits of experimental error are small.

The Schering bridge had a sensitivity of adjustment of 0·00003 as regards power factor. According to experiments by Churcher and Dannatt,* the power factor of the standard condenser may be taken as not greater than 0·00001 (it is probably less than this value), so that the accuracy of the power-factor results may be taken as of the order of $\pm$ 0·00002.

different samples. The maximum stress in these tests varied from 100 to 160 volts per mil.

Power-factor measurements carried out at a frequency of 50 cycles per sec. showed that the power factor at stresses under 20 volts per mil was of the order of 0·00025, but that above this stress it increased rapidly. It was noted that while the effective alternating-current resistance was much greater than the direct-current resistance at low stresses, the two became equal at a stress of 75 volts per mil.

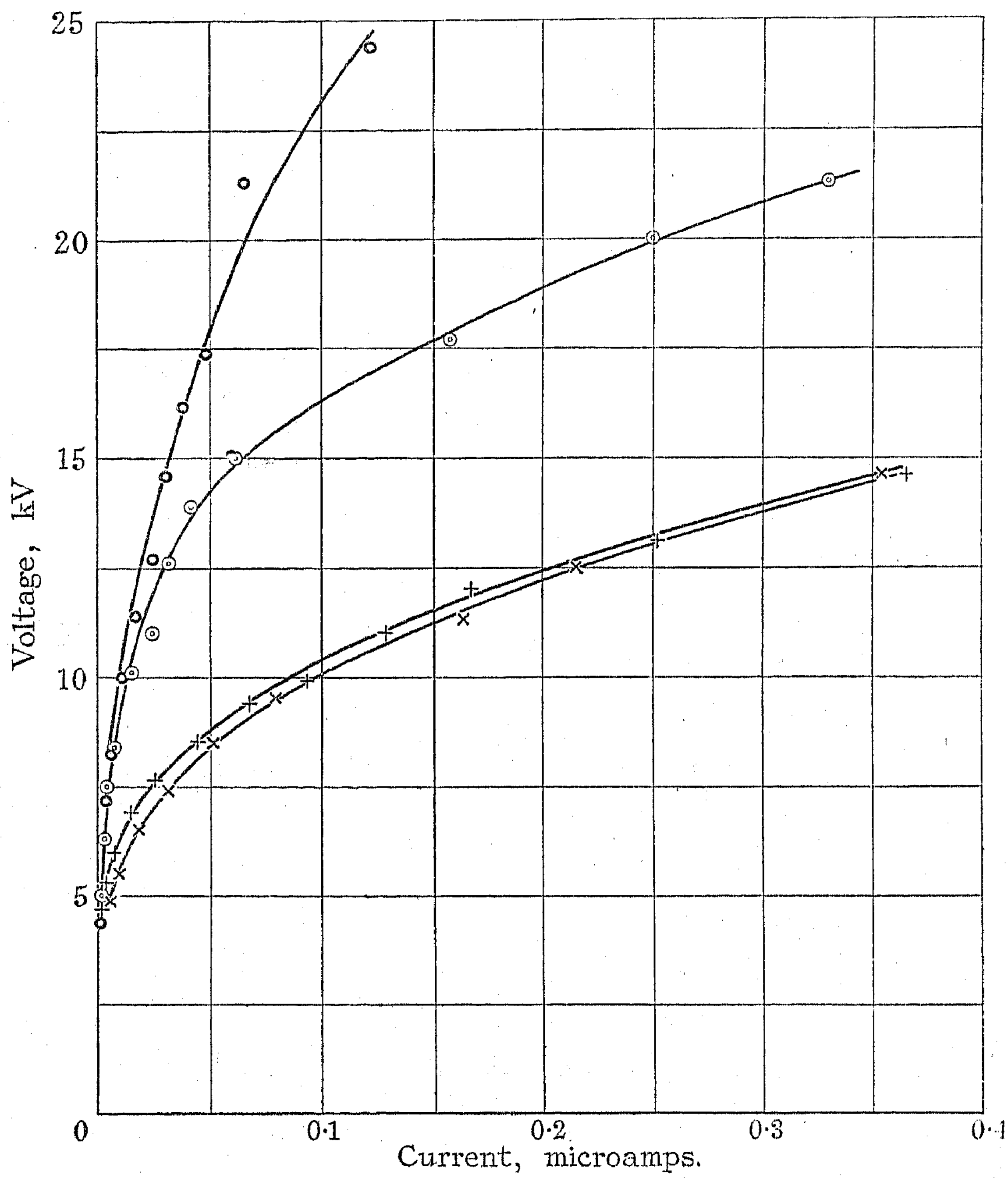

FIG. 5.

Electrode spacing 0·15 in.

FIRST SERIES OF TESTS.

A preliminary series of tests was carried out in the large test vessel shown in Fig. 3. The voltage/current curves obtained from four samples of the oil under direct stress are shown in Fig. 5, and the logarithms of the voltage and current are plotted in Fig. 6, from which it is seen that the relationship between the voltage and current can be expressed by a law of the form $I = kV^m$, the value of the index m varying from 2·6 to 3·9 for

* See Bibliography, (9).

The wide variation in resistance of the various samples at the same stress is probably due to incomplete dehydration of the oil. The amount of moisture present must, however, have been very small, earlier experiments having shown that if more than a trace of moisture was present the current became unstable at stresses above 10 to 15 volts per mil. Further experiments were therefore carried out in the small test vessel shown in Fig. 4, the small amount of oil required rendering dehydration a simpler process and reducing any possible

error due to impurities from the bulk of the oil being attracted into the region of high stress between the electrodes.

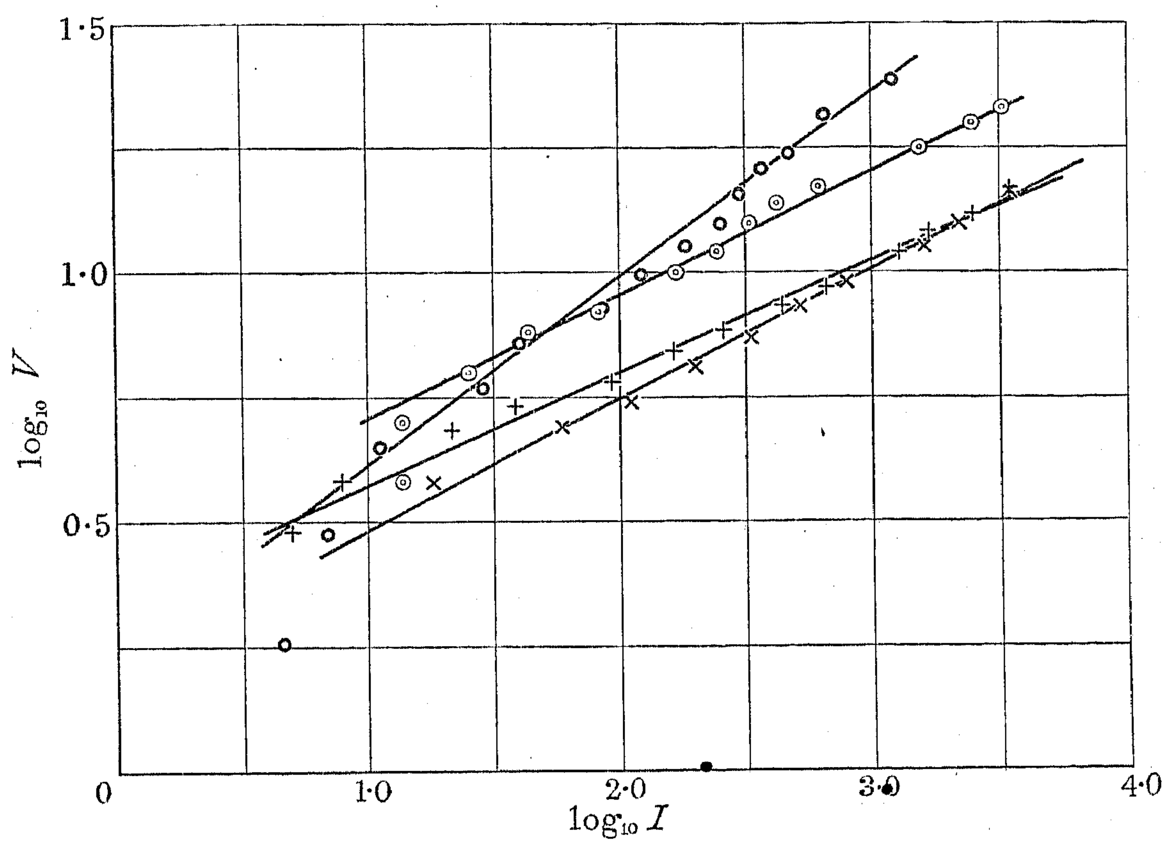

FIG. 6.

V is expressed in kilovolts.
I is expressed in microamperes $\times 10^{-4}$.

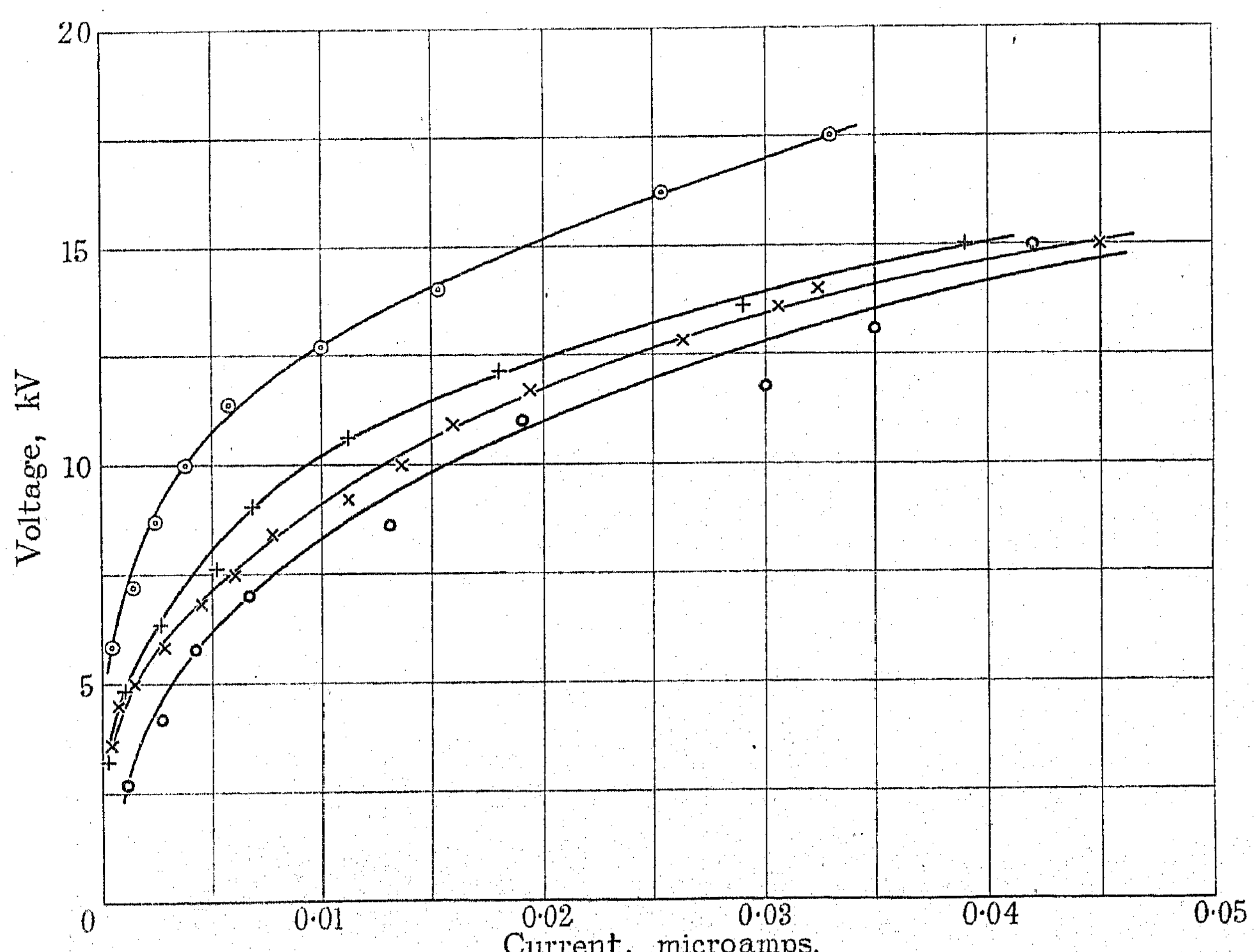

FIG. 7.

ments in which perfectly stable results were not obtained were discarded. The tests were carried out in the small test vessel with a spacing of 0·07 in. between the electrodes.

SECOND SERIES OF TESTS.

In these tests particular care was taken to avoid the access of moisture to the oil under test, and any measurements in which perfectly stable results were not obtained were discarded. The tests were carried out in the small test vessel with a spacing of 0·07 in. between the electrodes. The results of direct stress measurements on four samples of oil are shown in Fig. 7. The form of these curves is similar to that of those obtained in the

first series of tests, and, on plotting the logarithms of the voltage and current, as shown in Fig. 8, a similar law of the form $I = kV^m$ was found to hold. The value of

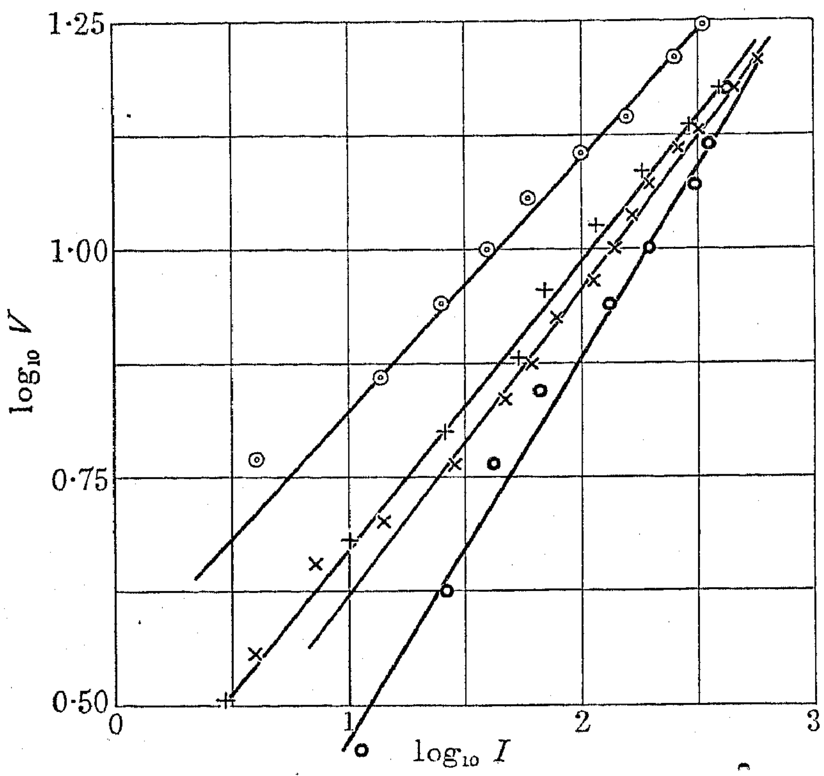

FIG. 8.
V is expressed in kilovolts.
I is expressed in microamperes $\times 10^{-4}$.

the index m varies from $2 \cdot 32$ to $3 \cdot 84$, with a mean value of $3 \cdot 23$, and is of the same order as in the first series though the resistivity of the oil is now much higher. At

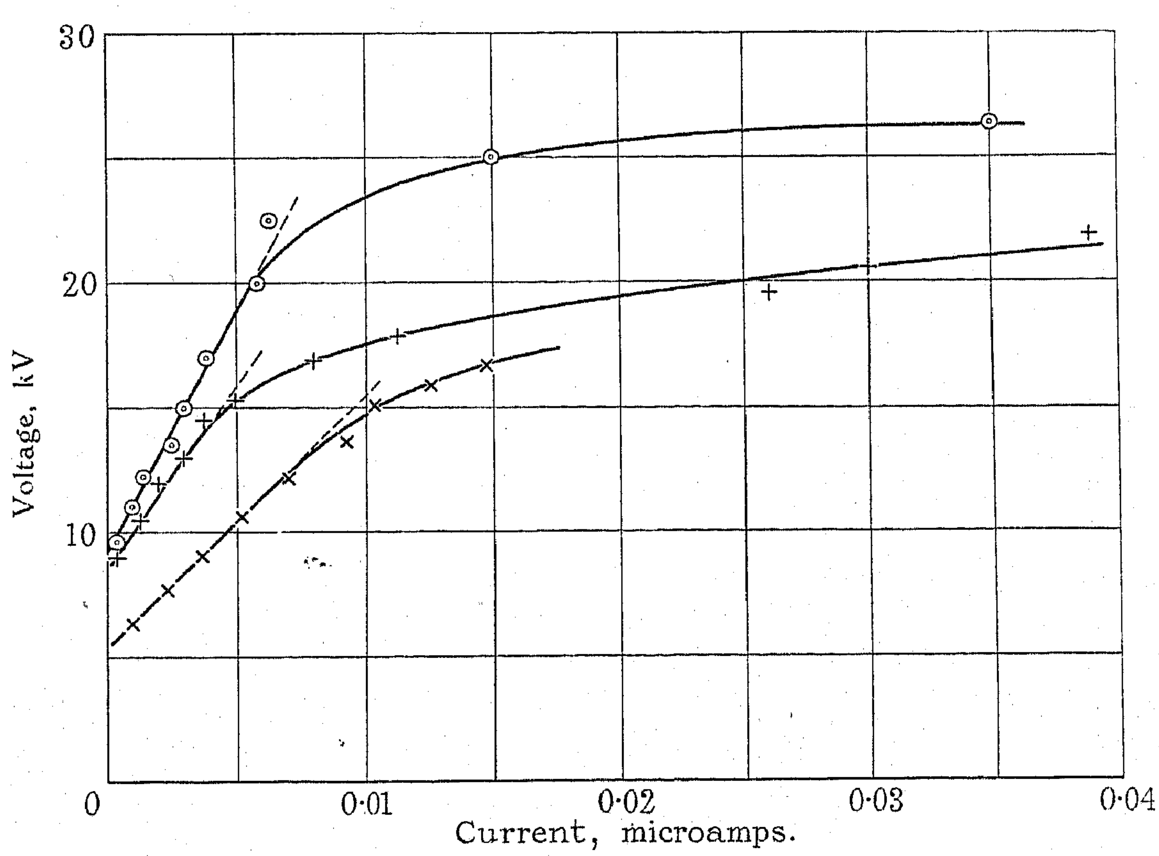

FIG. 9.

stresses above 200 volts per mil the resistivity of the various specimens approaches the same value, although there are considerable variations in the values at lower stresses.

Below a stress of 40 volts per mil, the current became too small to be measured, while above this stress the current increased rapidly. Black and Nisbet* suggest from their tests that a saturation current is observed in transformer oil at a stress of 17 kV per cm, or 70 volts per mil, and the curves now obtained indicate that no rapid increase of current occurs until a stress of this order is exceeded.

Tests on two samples of a poorer grade of oil yielded similar results, but in these cases the voltage/current curves could be expressed more accurately by a law of the form $I = I_0 e^{kV}$, I_0 and k being constants; though the curves also conformed approximately to the form $I = kV^m$.

The voltage/current curves could be accurately reproduced on reducing the voltage, provided a stress of 200 volts per mil was not exceeded. When the stress was increased above 200 volts per mil, somewhat lower values were obtained for the currents on decreasing the voltage, probably owing to some slight cleaning action of the current at high stresses.

THIRD SERIES OF TESTS.

This series forms a continuation of the previous series of tests, the purpose being to make a clearer study of the voltage/current characteristic between stresses of 50 and 200 volts per mil. The same test vessel was used, but the spacing between the electrodes was increased from $0 \cdot 07$ to $0 \cdot 15$ in. The curves obtained were all similar and had the form shown in Fig. 9, where three representative curves are plotted. All the curves show a straight-line portion in the region between 50 and 130 volts per mil, the equation of which can be expressed in the form

$$V = V_0 + nI$$

* See Bibliography, (4).

If V is expressed in kilovolts and I in microamps., the constant V_0 varies from 5·0 to 8·7, and n from 1 060 to 3 420. The values for six samples are tabulated in Table 1 along with the values of the power factor obtained for the same samples.

Further investigation of the form of the voltage/current curves showed that, if the results for the full range of voltage are considered, the voltage and current are again connected by a law of the form $I = kV^m$. The agreement is not so good for the lower parts of the curves owing to the linear law being true in this region, but the law $I = kV^m$ still holds approximately throughout the range. The relation can also be expressed approximately by an exponential law of the form $I = I_0 e^{kV}$, but the agreement is not so good as for the former law. The index m varies from 2·0 to 4·4 (Table 1), the wide range being apparently due to the attempt to make the relation fit the complete curves.

Power-factor measurements on the same samples of oil are also tabulated in Table 1. The power factor was found to be practically constant up to a stress of 70 volts per mil, the values varying from 0·00004 to 0·00008, while the capacitance remained constant irrespective of the stress. Instability of the bridge balance made it impossible to carry out accurate measurements at higher stresses, but it was evident that above this stress the power factor increased rapidly. Measurements of power factor may be subject to an error of $\pm$ 0·00002, but it is apparent that the power factor of a pure transformer oil is lower than that of the solid dielectrics in common use. This suggests that the use of oil-filled condensers may be a feasible proposition for cable testing and similar purposes.

TABLE 1.

Sample	V_0	n	m	Power factor
1	7·1	1 350	3·0	—
2	8·8	2 140	2·9	—
3	8·5	1 560	4·4	0·00008
4	5·0	1 060	2·3	0·00005
5	8·0	3 420	2·6	0·00004
6	6·3	2 740	2·0	0·00004

It was observed in the course of the direct-current measurements that the current at voltages above 15 000 volts, corresponding to a stress of 100 volts per mil, tended in some cases to decrease after the stress had been maintained for some time. The decrease did not exceed 10 per cent of the initial value of the current, and a steady condition was reached after 5 to 10 minutes. Prolonged application of the voltage produced no further decrease of the current, and the measurements of the final values of the current at various voltages could be reproduced accurately on raising or lowering the voltage. The decrease of the current was only observed on the first application of the higher voltages and was probably due to a slight cleaning action of the current, as the following experiment suggests.

A sample of oil had been allowed to stand for 2 days in the test vessel, and was then tested, when, as expected, the application of a small voltage produced a large conduction current. A voltage of 20 000 volts was then applied between the electrodes, producing a conduction current of 0·035 microampere, which increased after 1 minute to 0·038 microampere. The current then decreased, quickly at first and afterwards more slowly, until, after 50 minutes, the current was 0·0056 microampere, at which value it remained constant. After this, a voltage/current curve similar to that of the fresh samples was obtained, the points being reproduced accurately on a second test. This electrical cleaning action appeared to be possible only when the amount of contamination in the oil was small. The application of a high stress to an oil which had been insufficiently dried produced a current which increased rapidly with time and which appeared to be quite unstable.

SPECIFIC RESISTANCE OF THE OIL.

Values for the specific resistance at various stresses of seven samples of the transformer oil used in the second and third series of tests are given in Table 2. At a stress of 50 volts per mil the current in most cases was too low to be detected, and in calculating the specific resistance at this stress the value of the current in such cases has been taken as 0·0001 microampere on the assumption that any larger current could have been detected. The actual value of the current may have been smaller, and consequently the value of 4×10^9 megohms per cm cube assigned to the specific resistance at this stress must be taken as a minimum value.

TABLE 2.

Sample	Field strengths, volts per mil				
	50	100	150	200	250
	Specific resistance, times 10^7 megohms per cm cube				
1	400	66	20	11	6
2	100	22	11	9	—
3	100	16	8·1	5	2·4
4	400	28	13	—	—
5	400	18	1·5	—	—
6	400	38	17	—	—
7	400	25	22	—	—

These figures serve as a useful check on the purity of the oil. From data in a paper by Nikuradse,* the specific resistance of a highly purified transformer oil has been calculated as varying from $0{\cdot}87 \times 10^7$ to $1{\cdot}2 \times 10^7$ megohms per cm cube between stresses of 35 and 10 volts per mil respectively. These values are very much smaller than the values given in Table 2 at a stress of 50 volts per mil, in spite of the elaborate method described by Nikuradse† for the purification and dehydration of the oil. Welo‡ gives the specific resistance of transformer oil purified by successive vacuum distilla-

* See Bibliography, (6). † *Ibid.*, (1). ‡ *Ibid.*, (5)

tions as 5×10^{11} megohms per cm cube at a stress of 22 volts per mil. This is considerably higher than the value of 4×10^{9} megohms per cm cube obtained in many cases by the present author at a stress of 50 volts per mil, but it should be noted that Welo's value is obtained at less than half this stress in the saturation region where the maximum possible value is to be expected.

The comparison between the above figures suggests that the oil used by the present author was of a high degree of purity and that the method of dehydration was satisfactory.

Power Factor of the Oil.

The power factor of pure oil is of the order of 0·00005 up to a stress of 70 volts per mil, above which it increases rapidly. While at low stresses the direct-current resistance is much greater than the effective alternating-current resistance, it was observed that the two appear to approach equality at higher stresses. For less pure samples of the same oil (first series of tests) the power factor is 0·00025 at low stresses, and again the direct-current and the effective alternating-current resistances approach the same value at high stresses. It was noted that in all cases the capacitance of the sample was constant at all stresses, and that therefore the dielectric constant of the oil is independent of the voltage stress to which it is subjected.

Discussion of Results.

The experimental evidence indicates that the conduction in non-polar oils is of an ionic nature. The ionic theory of conduction predicts that, at low voltage intensities, space charges should be formed near the electrodes owing to deficiencies in the numbers of positive and negative ions in the regions of the positive and negative electrodes respectively. At any point in the liquid, equilibrium exists between the number of ions produced in the liquid, the number recombining, and the number carried away by the current, and this leads* to the equation

$$V = aI + bI^2$$

being obtained to express the relation between the voltage and current. Above a certain voltage intensity, the ions are carried away as quickly as they are formed; there is no recombination, and the current reaches a saturation value. Mie† has shown that, under these conditions, the potential gradient becomes uniform across the space between the electrodes, the effect being due to the distances by which the space charges extend from the electrodes increasing until they meet in the centre. The experimental work, to which reference has already been made, of Black and Nisbet on the form of the voltage/current characteristic and of Whitehead and others on the existence of space charges below the stress at which saturation occurs, is in full accordance with the theory. The source of the ions is not definitely known, but they may have their origin in impurities which tend to maintain a constant ionic concentration in the liquid or they may be ions of the liquid itself also tending to maintain a constant concentration. Jaffé‡ found that the conductivity of a highly purified oil could be halved by shielding the test vessel in lead; this suggests that ions produced by the effects of external radiation from radio-active materials or of cosmic rays may also play some part in the effect. The predominating effect of impurities on the conductivity, however, suggests that the main cause of the conductivity of oils arises from effects due to the impurities rather than in the molecules of the liquid itself.

* See Bibliography, (10). † *Ibid.*, (11). ‡ *Ibid.*, (12).

Up to the saturation value the current remains small, but above the saturation value a further rapid increase of current is observed, and it is in this third region that the foregoing experiments have been carried out. This rapidly increasing current is attributed to the formation of new ions by the effect of collisions between neutral molecules and the ions already present in the liquid, the effect being accentuated by the fact that these new ions may themselves attain sufficient velocity to generate further ions by collision.

In the second and third series of tests already described, the rapid increase of current occurred when the average stress exceeded 40 to 60 volts per mil. Below this stress the current was too small to be measured with the apparatus available, and consequently it is impossible to draw any conclusions regarding the initial voltage/current characteristic or the existence of a saturation stage. In the first series of tests the effect was not so marked, but again a rapid increase of current commenced at a stress of the same order as before, while below this stress the current was small and roughly proportional to the voltage.

The relation between the voltage and current can be represented in all cases by an equation of the form $I = kV^m$, the index m having a value of about 3. In a few cases the equation $I = I_0 e^{kV}$ represented the relationship more closely, but in these cases the former law was also approximately true. The relation was found to be true from a stress of 50 volts per mil up to the maximum stress, namely 300 volts per mil, at which measurements were obtained. Taking the breakdown value of transformer oil as 600 volts per mil, it appears that the relation is true up to the region of breakdown. When the oil under test is carefully purified, it is found that the voltage/current curve between 50 volts per mil and 120 volts per mil can be better expressed by a linear equation of the form $V = V_0 + nI$. The rate of increase of the current in relation to the voltage is thus constant up to 120 volts per mil.

It follows from Joffé's work* on breakdown by ionization that Poole's equation† for solid dielectrics, namely

$$\log G = a + bV$$

G being the conductivity and V the voltage, can be deduced mathematically from the assumption of ionization by collision such as is suggested as the cause of the present effects. Although this law is not followed exactly in the present case, it should be noted that the equations

$$\log G = a + bV,$$
$$I = I_0 e^{kV},$$
and $$I = kV^m \text{ (where } m \text{ is about 3)}$$

* See Bibliography, (13). † *Ibid.*, (14).

all give very similar curves and might all be regarded as fitting the present voltage/current curves to a fair approximation. Hence it may be concluded that, as far as it can be deduced from the form of the voltage/current characteristic, the mechanisms of conduction in liquids and in solids at high stresses are the same, and that in both cases ionization of neutral molecules by collision with ions already present in the substance will explain the observed effects.

An alternative explanation of the rapid increase in the current at high stresses lies in the attraction of impurities from the bulk of the oil into the region of high stress between the electrodes. Under these conditions the high conductivity at high stresses might have been expected to persist for some time when the stress was reduced, whereas actually the conductivity decreased immediately the stress was reduced. Moreover, the same law applied to the results of all the tests irrespective of the purity of the oil or the amount of oil surrounding the electrodes. Thus, though such an effect may furnish a partial explanation of the increase in conductivity in some cases at comparatively low stresses (e.g. in the first series of tests), an additional effect such as ionization by collision must be introduced to account for the greatly increased conductivity at stresses above 50 volts per mil.

It should be noted that the rapid increase of current under direct stress commences at approximately the same value as the r.m.s. value of the stress at which the power factor begins to increase. This suggests that both effects are due to the same cause.

It is difficult to suggest an explanation of the linear relation between the voltage and current which appears to be true in the transition stage between the saturation current and the rapidly increasing current. The form $V = V_0 + nI$ might suggest that there is a polarization voltage V_0 set up in the liquid in opposition to the applied voltage, but such a polarization voltage is incompatible with the deduction from the ionic theory that the stress distribution becomes uniform when the saturation current is reached,* a result which has been confirmed experimentally. The effect may be due to some such cause as follows. At the lower stresses above the saturation limit an ion requires to cover a comparatively large distance before acquiring sufficient velocity to ionize a molecule by collision. Consequently only ions with a long distance to travel are effective, but with increased voltage the ions will acquire the necessary energy in a much shorter distance and their acceleration will be hindered less by ineffective collisions. A much less rapid increase of current is therefore to be expected in the earlier stages above the critical voltage at which ionization by collision first occurs, and this may explain the approximation of the voltage/current characteristic to a linear relation in this region. A somewhat similar explanation is generally advanced to explain the effect whereby the breakdown strength of a solid increases as the thickness of the specimen is reduced.

* See Bibliography, (11).

The author desires to thank the Vacuum Oil Co., Ltd., for providing the oil used in these tests. The work was carried out in the High-voltage Laboratory of the Municipal College of Technology, Belfast.

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A CATHODE-RAY OSCILLOGRAPH EQUIPMENT EMBODYING A HIGH-VOLTAGE, GAS-FILLED, SEALED-GLASS OSCILLOGRAPH TUBE.

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SUMMARY.

A description is given of an oscillograph equipment for high recording speeds incorporating a recently developed type of high-voltage, gas-filled, cold-cathode, sealed-glass oscillograph tube, and therefore requiring no pumps. Constructional details and characteristics of the tubes and all accompanying accessories necessary for the operation of the oscillograph, with their arrangement in a common housing, are given. The means of beam control are described; also the mode of action of electromagnetic and of electrostatic deflection circuits for cyclic and single-sweep phenomena, and for controlled and uncontrolled events, is explained. Specimen oscillograms illustrating each case are given.

As far as possible, the more recent features only of cathode-ray oscillograph technique are emphasized.

TABLE OF CONTENTS.

INTRODUCTION.

In the development of the high-speed, cathode-ray oscillograph several stages can be observed. At first, sealed-glass tubes and cathode voltages up to 30 kV were used; there was a single concentrating coil and the simplest form of photography was employed, namely an ordinary camera outside the tube. With such means, events having a duration of 10^{-3} sec. could be recorded.*

In the next stage, new artifices were introduced to increase the capabilities of the instrument. Among the chief modifications was the use of internal photography by Dufour, who allowed the electron beam to impinge directly on the photographic plate by placing the latter inside the evacuated tube.

To maintain the vacuum, and to re-create the vacuum after renewal of plates, it was necessary to keep pumps in continuous operation. For convenience in working, nearly all the parts of the oscillograph were made of metal.

An alternative method of employing the beam direct was made possible by the use of the Lenard window—a thin metal foil supported by a grid, at the recording end of the oscillograph; but here again pumps had to be in continuous operation.

In addition to these means, the use of the second concentrating coil and the beam trap, the division of the tube into discharge and deflection chambers with different degrees of vacuum, and the introduction of higher anode voltages and metal discharge-tubes, made the metal-tube, cathode-ray oscillograph into an instrument of great capability. A writing speed of 1/5th the velocity of light was obtained,† and thus the limit set to the cathode-ray oscillograph by the finite velocity of the electron beam‡ was approached. The successful achievement of this second stage can be ascribed mainly to Dufour, Wood, Rogowski, Norinder, Berger, Knoll, Ackermann, Burch, Whelpton, Miller, and Finch.

The writing intensity being now ample, it was possible to consider the simplification of the apparatus, which in many cases had become complicated.

Coming then to the next stage, representing one aspect of the work of recent years, it will suffice to mention some investigations undertaken at the Technische Hochschule, Aachen, directed to the possibilities of a return to simple external photography with lens and camera. The work of J. M. Dodds§ proved that with external photography everything could be done‖ that was formerly possible with internal photography.

Since with the improvements mentioned the brilliancy was sufficient to dispense with the exposure of the film to the direct beam, the need for retaining continuously-working pumps was lessened, and sealed-glass tubes for similar performances were considered and tried. The

* See the work of Braun, J. J. Thomson, Wehnelt, MacGregor-Morris, and Zenneck. This speed is comparable with that obtainable with the large number of modern hot-cathode low-voltage sealed tubes of the gas-focusing or high-vacuum types (Wehnelt, MacGregor-Morris, Johnson, Ardenne, Zworykin).

† See Reference (1). ‡ *Ibid.*, (16). § *Ibid.*, (2).

‖ With such methods, very high cathode voltages (up to 95 kV) were required for the fastest phenomena.

first attempts in this direction by Rogowski and his assistants at Aachen were successful.* By these means, a great simplification was effected. As here the cathode voltage cannot much exceed 50 kV, the writing speed is not so high as, for instance, in the case where metal discharge tubes using higher voltages are employed. Nevertheless, the sealed-glass tube without pumps can deal satisfactorily with most problems occurring in laboratories and test rooms, as will be evidenced by the oscillograms reproduced in Plate 1, facing page 664.

The remainder of this paper will deal with an equipment incorporating such a tube. This instrument† has most of the characteristics which are desirable from the point of view of teaching and research. For these purposes both electromagnetic and electrostatic time-base operation are provided, and the equipment is arranged for the recording of cyclic and transient phenomena whether controlled or uncontrolled. The instrument is assembled complete with its accessories and is made transportable. Owing to the absence of pumps, with the attendant disadvantages of air leaks and the time required to evacuate the tube, the instrument is immediately ready for use when required.

The Oscillograph Tube.

For the purpose of description it will be convenient to consider the glass tube‡ under the following headings: discharge tube with cathode (A—B, Fig. 1); metal shield carrying anode and other diaphragms, trap, and deflection plates (B—C, Fig. 1); portion of tube for visual and photographic observations (C—D, Fig. 1).

Discharge Tube with Cathode.

The original difficulty in connection with the cold-cathode sealed tube was crater-formation in the cathode, which soon rendered it necessary to change the cathode. Although a simple matter with the metal tube, this was impossible with a sealed-glass tube having a normal cathode. This difficulty was overcome by using a movable cathode,§ consisting of a loose metal ball (e, Fig. 1) the position of which could easily be moved by lightly tapping the tube, thus presenting a new face towards the anode. This sphere, which is made of aluminium, has a diameter of 18 mm, and the internal diameter of the discharge tube is 2 mm greater than the cathode diameter. The arrangement of the cathode, with the movable ball, is shown in Fig. 1.

Metal Shield with Anode, Beam Trap, and Deflection Plates.

The glass tube serves merely as a vacuum chamber. The anode, deflection plates, etc., are all attached to a 65-mm diameter aluminium tube, which serves both as a screen and as a structural element for ensuring correct alignment, etc., of the diaphragms and plates. Fig. 1 shows a section of the tube.

For trapping the beam, two trap chambers are provided, the use of which is described later. These are formed in the cylindrical casing by three transverse circular plates, d_1, d_2, d_3, each having at the centre an aperture. The beam passes through the first and narrowest aperture—the anode opening d_1 of 0·8 mm—to the first trap chamber. The deflection plates t, t, are just past the anode aperture (see Fig. 1). The end of this chamber is formed by the second diaphragm d_2 and aperture of 3 mm diameter. The deflection plates in the second chamber t', t', are connected in parallel with those in the first chamber. The second chamber terminates with the third aperture d_3, of 12 mm diameter. The first two apertures are 140 mm apart, and the second two are 290 mm apart. The method of assembly of the trap plates and diaphragms is shown in Fig. 1.

After the third aperture, i.e. outside the trap chambers, come the time-base deflection plates c, c; and then perpendicular thereto, two pairs of plates a, a; b, b for connection to external circuits which are under investigation.

All the glass seals s, s for the incoming leads are placed at the screen end of the tube, thereby leaving the remainder conveniently free for the concentration coils. The bushings for the incoming leads and for the conductors through the middle ray-trap partition are made of steatite instead of (as formerly) glass, and arranged so as not to intercept the beam during operation.

Screen.

The diameter of the screen is 14 cm. The fluorescent substance used on it is zinc sulphide, which is fused on the inside of the end of the tube. Compared with other substances, at high voltages, zinc sulphide gives the most brilliant spot, and its characteristic after-glow is very useful when observing single-sweeps. The image remains for some minutes, so that it is not only easily seen and photographed but also easily traced. The spot is particularly bright when viewed from the inner side of the screen, though even from the normal position of the camera, at the end of the tube, the light may be unpleasantly intense.

Demonstration Tube.

In addition to the tube just described, a further tube is provided for demonstration purposes. This tube has a large screen of 22 cm diameter. It is not, however, equipped for uncontrolled events. Otherwise it is built on the same lines as the tube previously described, but with one electrostatic trap-chamber only. Owing to the large deflecting voltages needed for such large images on the screen, this tube is usually worked with electromagnetic deflection and beam trap.

The lengths of the tubes described above are 135 and 150 cm respectively.

Arrangement of Complete Apparatus.

The whole apparatus, as Fig. 2 shows, is rigid and transportable. On the left is the high-voltage equipment, and on the right and in the middle are the controls and time-base equipments. The upper part is the

* See Reference (3).

† The instrument was built for the Electrical Engineering Laboratories of the Royal Technical College, Glasgow, to the specification of Prof. S. Parker Smith. The oscillograph tubes were designed and constructed in the Electrotechnical Laboratories of the Technische Hochschule, Aachen, under the supervision of Prof. W. Rogowski, by Dr. C. E. Szeghö, as were certain components of the time-base and beam-control equipments. The instrument was built and supplied by Dr. Hans Rumpff, of Bonn.

Various modifications have since been effected, such as a rearrangement of the electrostatic time-base equipment, and simpler tubes have been designed by the authors. Such a tube is the one used for the demonstration; it was manufactured by Mr. Cuthbert Andrews, of London.

‡ See Reference (8).

§ See References (3) and (8).

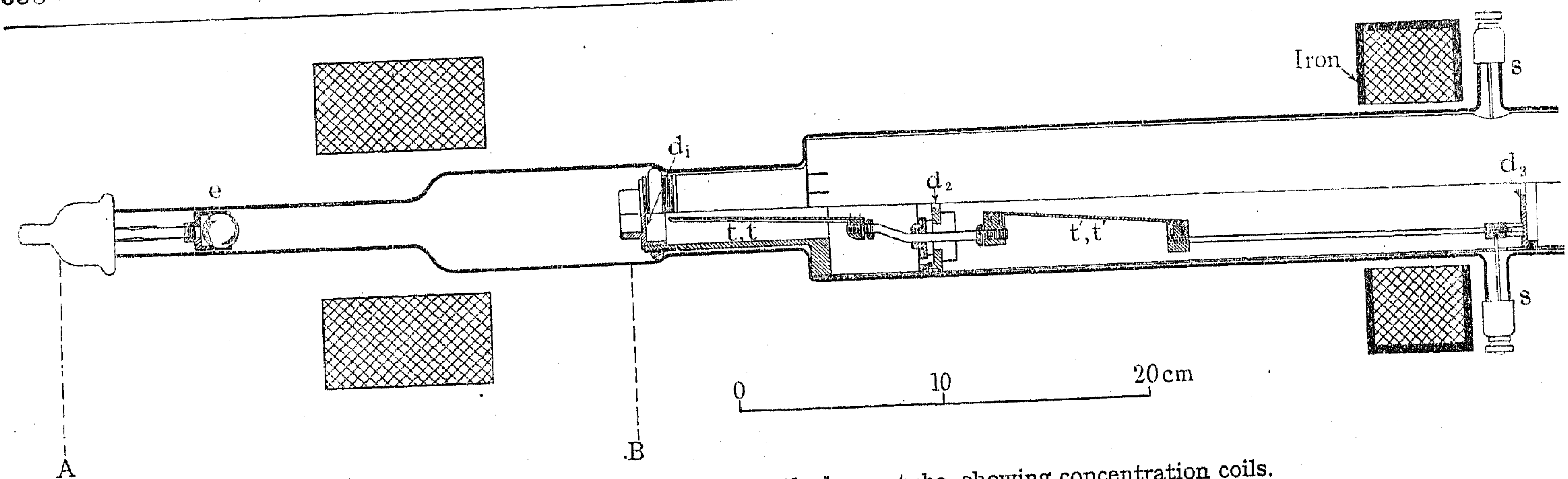

FIG. 1.—Sealed-glass high-voltage cathode-ray tube, showing concentration coils.

enclosure in which the particular tube in use is inserted, resting on a wooden carrier. A lead screen is provided near the anode to protect the operator from X-rays.

High-Voltage Equipment.

The high-voltage equipment works with half-wave rectification. The transformer voltage is adjustable from 30 to 40 kV (r.m.s.). It has one secondary terminal directly earthed. A large smoothing condenser (0·1 μF) is connected across the transformer and valve. The insulated filament transformer for the rectifier valve is supported on the main transformer (Fig. 2, left). The condenser is housed in the bottom iron tube, which forms a rigid connection between the left- and right-hand sides of the apparatus. This disposition of the components permits the high-voltage lead to be short and the smoothing resistance to be near the oscillograph, ensuring a steady discharge. A milliammeter serves as a continuous check on the condition of the vacuum.

Coil Arrangements.

Control of the beam is effected by means of coils mounted in the tube housing (Fig. 3). The method of control is as follows. First, the action of the earth's field, which would cause a deflection of the spot on the screen of 2 to 3 cm with the tube lying horizontally, must be compensated. For this purpose two pairs of rectangular coils at right angles to one another are employed, extending the whole length of, and made integral with, the oscillograph-tube housing. These, like the rest of the coils, are excited from a 24-volt battery accommodated in the lower half of the right-hand portion of the oscillograph. The current through the earth coils is adjusted so that the spot falls in the middle of the screen.

Particular care must now be taken that as many as possible of the electrons arriving at the anode pass through the aperture therein. The diverging beam which is emitted from the cathode is first concentrated by means of a longitudinal magnetic field produced by the "initial concentration coil" in such a manner that the narrowest section of the beam occurs just at the anode aperture.* From here the ray again diverges, and it is now concentrated by a second or "main" concentration coil so that the smallest ray section falls on the screen.

The initial concentration coil thus lies between the cathode and anode, whilst the main concentration coil must be near the last aperture (Fig. 1). To make the latter coil short, it is ironclad.* Both coils are adjustable by means of 3-point suspensions, and in addition can be turned about their vertical axes.

The spot thus obtained has great intensity,† and is focused in the centre of the screen. Hence, in order that writing may begin from one side, the beam must be deflected by a transverse magnetic field produced by means of the "biasing coil." The biasing coils must have a specially uniform field so as not to cause distortion of the writing. The most favourable position for them is over the time-base plates (Fig. 3). The potentiometers and regulating resistances for these coils are arranged on the centre panel.

Photographic Auxiliaries.

As the coils and other controls are adjusted from the front of the instrument, it is arranged that the trace on the screen may be observed from the same position by means of an inclined mirror, which enables the inside of the end of the tube to be seen. Photographs, however, are usually taken at the end of the oscillograph tube. (All the photographs reproduced in this paper were so taken.) For this purpose the camera is placed to the right of the apparatus. It has an f-1·8 lens of 7·5 cm focus. The plate size used is 4·5 × 6 cm. Film pack can also be used.

Since the oscillograph compartment can be made light-tight by means of sliding doors, there is no need to do the photography in a darkened room. Opening the plate slide merely uncovers the plate; the exposure time starts only when the spot begins to cross the screen. One advantage of the glass-tube form of construction with external photography is that the trace on the screen is seen while it is being photographed, and thus the operator can tell whether the exposure has been successful before the plate is developed.

CHARACTERISTICS OF OSCILLOGRAPH TUBE.

Discharge Tube.

Some workers have made the observation that when glass discharge tubes are employed the discharge is

* See References (7) and (9); also page 71 of Reference (15).

* See Reference (9).

† Using maximum concentration with the initial coil and with the main coil suitably adjusted, the spot has an apparent visual size of less than 1 mm, whilst measurements from photographs show a thickness of trace of 0·2–0·4 mm.

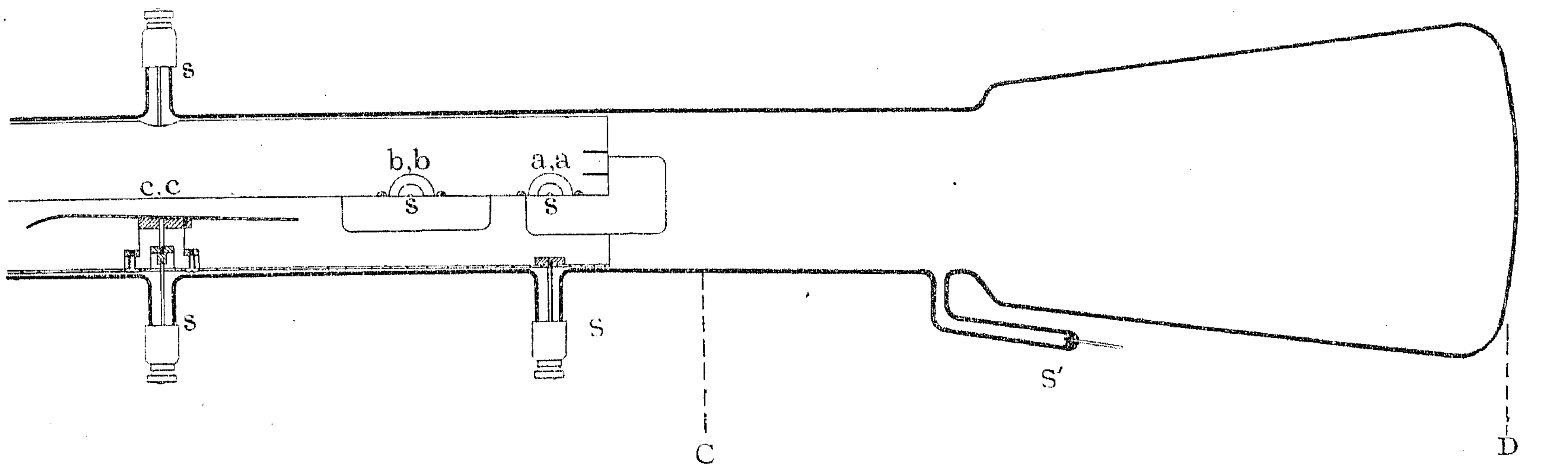

FIG. 1 (continued).

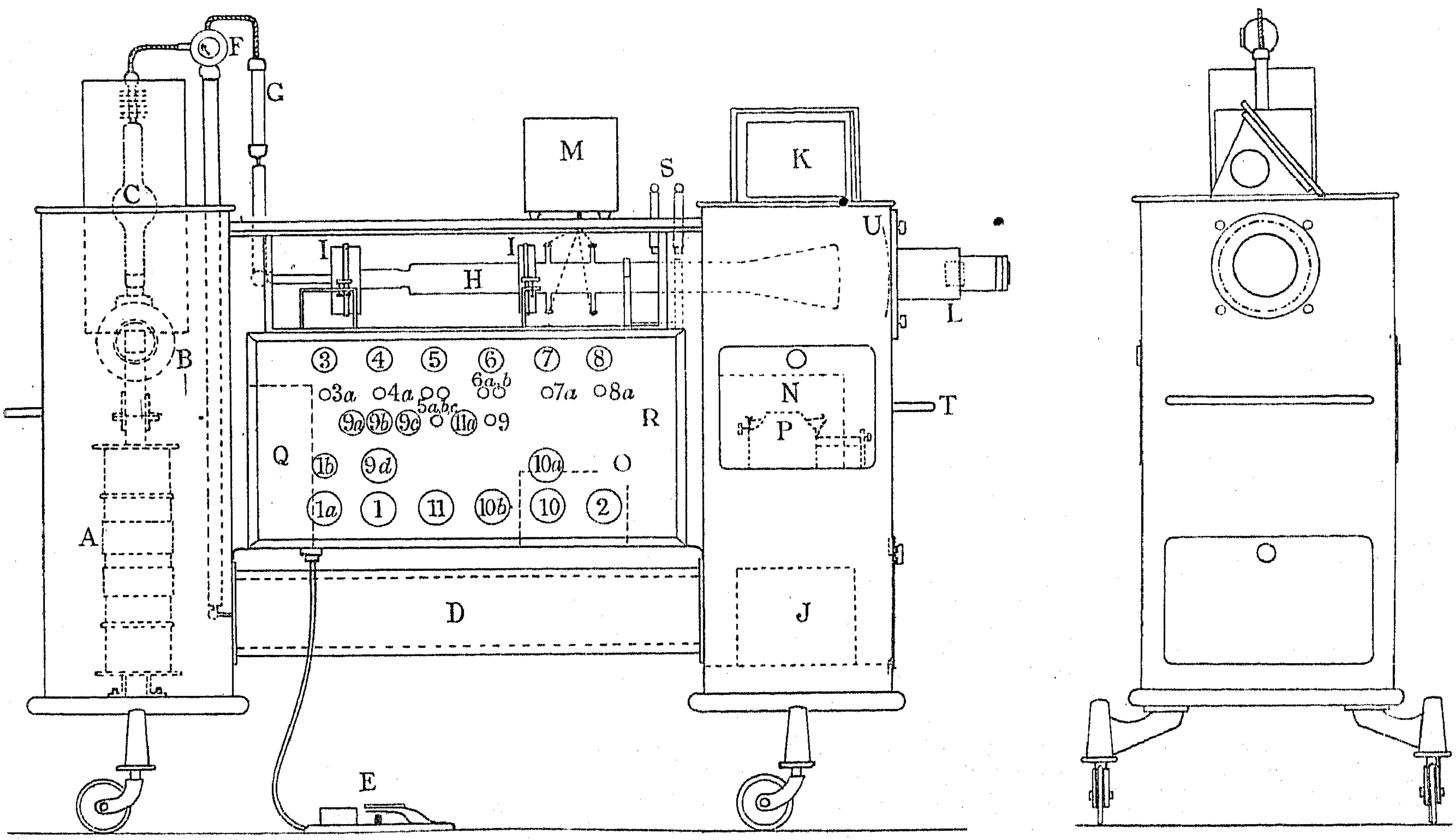

FIG. 2.—General arrangement.

A. High-voltage transformer.
B. Rectifier-valve filament transformer.
C. Rectifier valve.
D. High-voltage smoothing condenser.
E. Foot switch for control 1*a*.
F. Milliammeter.
G. Resistance.
H. Oscillograph tube.
I. Concentration coils.
J. Battery compartment.
K. Viewing mirror.
L. Camera.
M. Electrostatic time-base equipment.
N. 2 000-volt supply for electrostatic time-base equipment.
O. Electromagnetic time-base equipment.
P. Relay switch for electromagnetic time-base equipment.
Q. Periodic time-base equipment.
R. Control panel.
S. Terminals for connection to circuits under investigation.
T. Handles for moving oscillograph equipment.
U. Position of screen of demonstration tube.

Controls.
1. Rectifier filament heating switch.
1*a*. High-voltage transformer supply switch.
1*b*. Transformer supply voltage regulator.
2. 24-volt supply main switch.
3, 3*a*. Initial concentration-coil rheostat and switch.
4, 4*a*. Main concentration-coil rheostat and switch.
5, 5*a*, *b*, *c*. Biasing-coil rheostat and switches.
6. Relay-coil rheostat.
6*a*, *b*. Trap-coil switches.
7, 7*a*, 8, 8*a*. Earth's-field compensation coils; rheostats and switches.
9. Periodic time-base: valve filament switch.
9*a*, *b*, *c*, *d*. Periodic time-base: synchronizing, frequency, and amplitude controls.
10. Electromagnetic time-base supply switch.
10*a*. Variable inductance for electromagnetic time-base equipment.
10*b*. Relay operating switch.
11. Electrostatic time-base supply switch.
11*a*. Electrostatic time-base: time-valve filament rheostat.

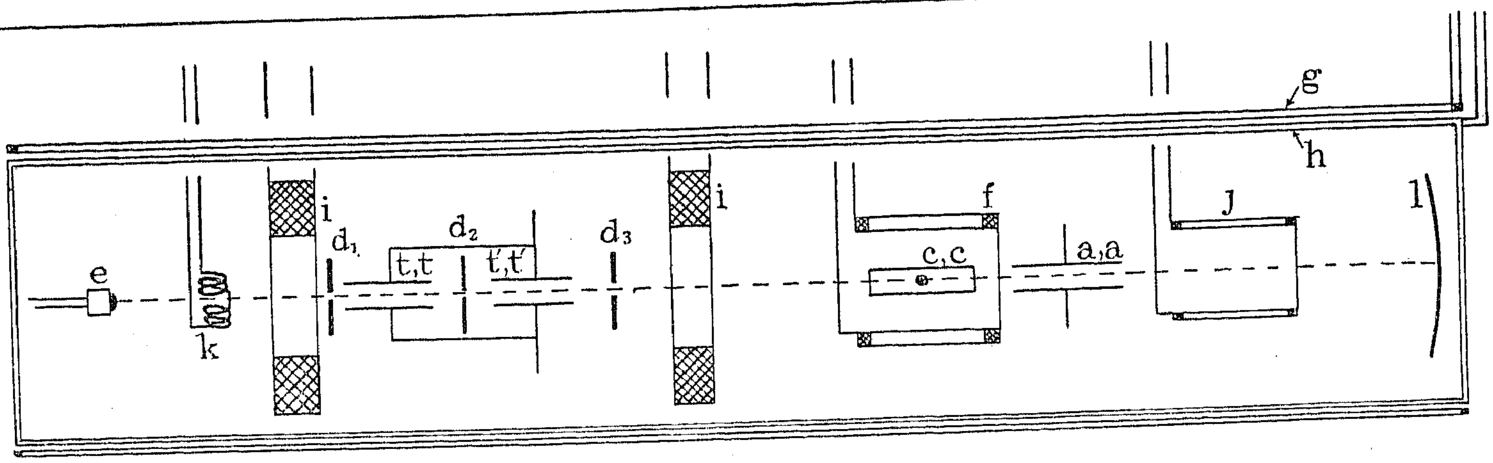

FIG. 3.—Schematic diagram.

a, a. Deflection plates.
c, c. Time plates.
t, t, t', t'. Trap plates.
d_1, d_2, d_3. Diaphragms.
e. Cathode.
f. Biasing coil.
g, h. Earth's-field compensation coils.
i, i. Concentration coils.
j. Electromagnetic deflection coil.
k. Trap coil, usually situated between initial concentration coil and anode.
l. Screen.

unsteady.* This may be found in many cases to be due to the presence of impurities such as vapour (mercury, water, grease, oil), or a moisture film on the inside of the discharge tube; as shown, for instance, by the experiments of Gabor† and Dodds‡ in respect of the condensation on the cathode of mercury vapour from the pumps.

Owing to the particular method of construction§ of these sealed tubes, all impurities are removed. This is ensured by mechanical and chemical cleaning, baking of the tube (400° C.), and freezing-out of impurities by liquid air; and since, after sealing, there is no possibility of ingress of such impurities, the discharge is particularly steady.

Unless continuous operation is required, the heating is inappreciable|| and no provision for cooling is necessary, even the simple expedient of using a fan being dispensed with.

Vacuum.

The tube is filled with hydrogen at a pressure of 5×10^{-2} mm of mercury. When hydrogen is employed a brighter spot is obtained on the screen than with air, and also the cathode emission point¶ has a longer life. When, after the tube has been used for some time, the gas pressure falls owing to the "clean-up" effect, i.e. when the tube becomes too hard, it is only necessary to apply a small methylated-spirit lamp for a short time to the end of a palladium tube which is sealed into a glass tube s' (Fig. 1) projecting from the oscillograph tube (as with certain X-ray tubes). This allows hydrogen to diffuse into the oscillograph.

The best working voltage for the tube is about 50 kV, with a discharge current of 1–1·5 mA.** The dependence of this current on the degree of initial concentration is shown in Fig. 4. The explanation of these curves is not immediately clear, but it is probably concerned with charges on the walls of the discharge tube, or the modification of the electron paths by the magnetic field. It should be noted that this provides a method of regulating the discharge current, and therefore the intensity of the trace, independently of the cathode voltage and deflectional sensitivity. When it is desired that a higher proportion of electrons should reach the fluorescent screen than is obtainable with initial and main concentration coils only, a third or "auxiliary" concentration coil* is used between the initial and the main concentration coil, thus concentrating the beam so that it is not restricted by the intermediate aperture in the trap chambers. The authors have observed that when the cathode is not

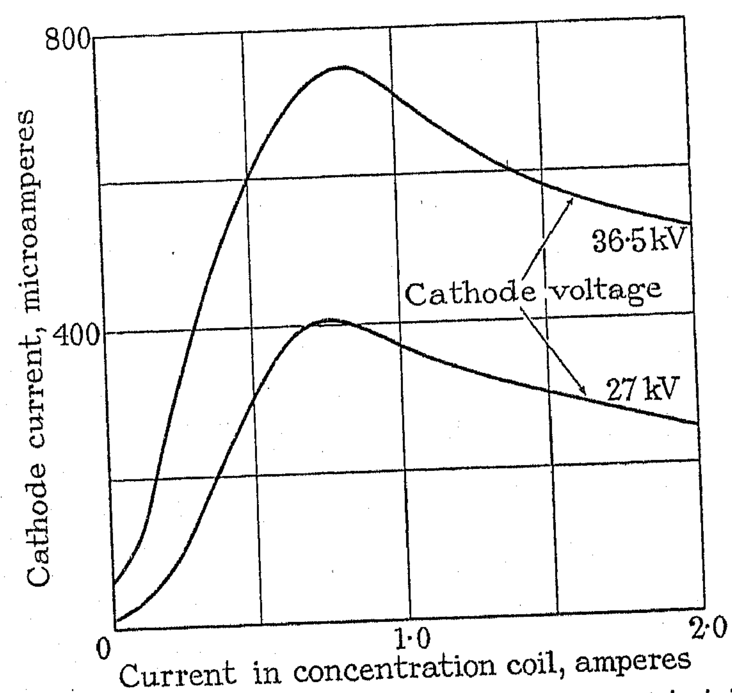

FIG. 4.—Dependence of cathode current on current in initial concentration coil.

excited, the use of this coil with certain field strengths results in discharges when a voltage is applied between the trap plates. A suggested explanation of this phenomenon is that, for the voltage applied (2 000 volts), the distance between the plates is too small for discharge to occur owing to the small accelerating path of the electrons for the particular gas pressure, but when a transverse magnetic field is applied the motion of the electrons is such that the effective distance is increased and discharge occurs. Somewhat similar effects have been noted in connection with gas discharge phenomena.†

* See References (4), (5), and (6).
† *Ibid.*, (7).
‡ *Ibid.*, (2).
§ *Ibid.*, (8).
|| Intermittent work naturally results in small heating; whilst continuous transmission-line recording requires only comparatively low cathode voltages, since the phenomena concerned are relatively slow, and this again results in small heating.
¶ See Reference (9).
** The influence of the cathode current on the high-voltage equipment is discussed by Beyerle (see Reference 18).

* See Reference (13).
† *Ibid.*, (19).

Deflection Plates.

The capacitance of the deflection plates has been kept low, and amounts to only a few centimetres. The resistance between the plates, measured at 500 volts, was found to be greater than 10^8 ohms in each case.

The sensitivities of the various deflection plates (Fig. 1) at cathode voltages of 15 and 50 kV respectively, expressed in mm per 100 volts, are as follows: Plates *a, a,* 7·5 and 2·3; plates *b, b,* 8 and 2·4; plates *c, c* (time), 17 and 5. Plates *a, a,* and *b, b,* may be used in parallel or in opposition for other sensitivities, or one of these pairs of plates may be used to superimpose a timing oscillation on the wave to be recorded. The deflection plates will withstand a constant applied voltage of 2 500 volts.

Since this is a gasfilled tube, it might be thought that the threshold effect would be evident; but deflection/voltage measurements made with a cathode voltage of 15 kV have failed to detect any such effect.

Recording.

Since the spot must be intense enough to write at a speed of several hundred kilometres per sec., it must not remain focused on the screen beyond a fraction of a second. The energy of the beam may be sufficient not only to destroy the fluorescent surface but actually to pierce the glass. An indication of the brilliancy of the

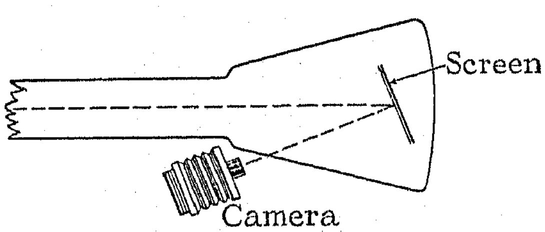

FIG. 5.—Photography with inclined metal fluorescent screen.

large spot (2·6 cm diameter) produced by the normal cathode voltage, using only the first concentration coil, may be gathered from the fact that an intensity of about 10 candle-power was obtained on the longitudinal axis at the end of the tube.

Curved screens are employed, the radius of curvature being approximately equal to the distance from the deflection plates. Thus measurements made from the trace on the screen show no distortion, though a slight error may be present in photographic recording. It is desirable to include a certain amount of after-glow in the exposure. Naturally, the screen must be allowed to become free from the after-glow of previous exposures.

With certain tubes of this type, movable fluorescent screens have been used inside the tube in addition to the screen on the end wall. This construction offers certain advantages.*

* The light intensity is somewhat greater when observed from the front instead of from the back of the fluorescent surface, and, by using an inclined screen, photographs may be taken through the side wall of the tube of this brighter side, as shown in Fig. 5. The distortion due to the conical wall is negligible, as has been shown by photographing a piece of squared paper attached to such a screen. The use of such metal screens provides also for a change of fluorescent surface if disintegration occurs, and removes the danger of damage to the glass.
The screens may be provided with a strip of carbon at one side, on which the beam falls if incompletely trapped, or if untrapped but deflected to one side. This prevents fogging of the screen. A similar advantage may be obtained when the screen on the end wall of the tube is restricted to a rectangular area in the centre.
When movable metal screens are employed the thickness of fluorescent material may with advantage be made greater, since this is not limited by considerations of light transmission to the reverse side of the screen, as in the case where the screen is placed on the end of the tube.

TIME-DEFLECTION DEVICES.

The oscillograph is provided with all the accessories required to carry out the several measurements mentioned in the Introduction. This means that the times of traverse of the devices for controlling the time-base have an unusually wide range, namely about 1 : 10^5. These accessories are arranged according to convenience. At

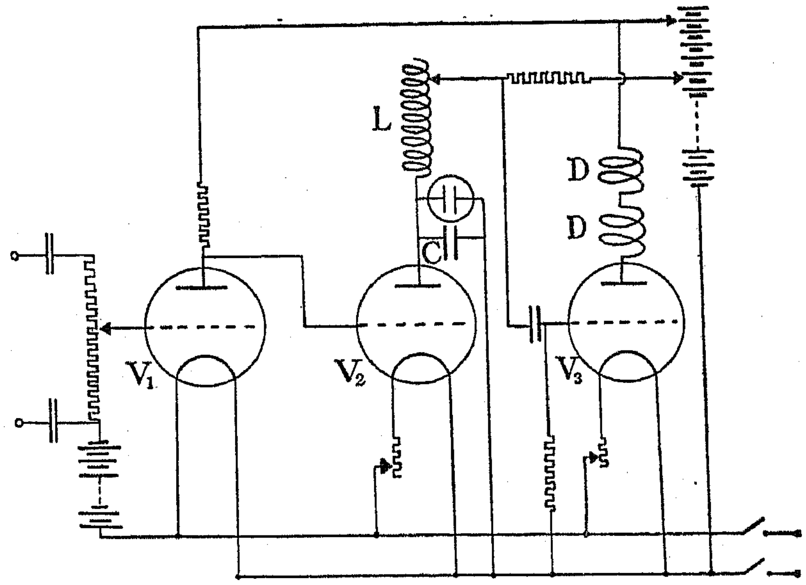

FIG. 6A.—Periodic time-base circuit, with electrostatic trapping.

the back of the control panel there is an equipment for the production of a periodic time-base for cyclic phenomena; also an electromagnetic time-base circuit for single-sweeps. A solenoid-operated switch to relate the operation of this electromagnetic time-base and the electromagnetic beam-trap circuit with the phenomena under investigation is seen in the compartment on the right of Fig. 2.

The voltage supply for the electrostatic time-circuit is also in this compartment, and is seen behind the switch. The time-base circuit itself, seen above the tube housing in Fig. 2, is placed as close as possible to the terminals of the trap and sweep plates.

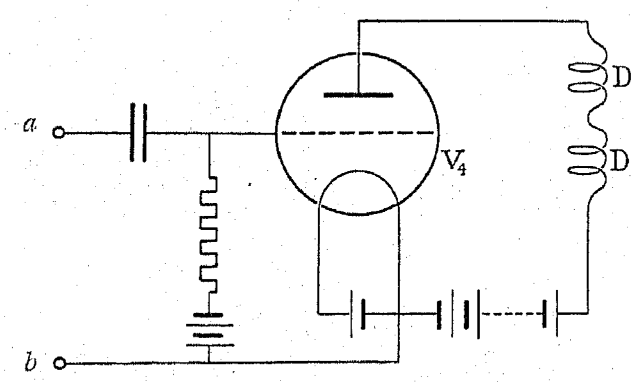

FIG. 6B.—Modification of Fig. 6A. *a, b* are connected between anode and filament of V_2.

Periodic Time-Base and Synchronizing Device.

For periodic phenomena a time-base operating synchronously with the wave under investigation is required. According to the number of cycles desired on the screen, the time of traverse of the time-base must be a corresponding multiple of the period of a cycle. For this equipment a thermionic valve with dynatron (i.e. falling) characteristic as used by H. Kroemer* was employed.

The circuit of this device is seen in Fig. 6A. The

* See References (10) and (11).

first valve V_1 imparts impulses in synchronism with the cycles of the wave under investigation to the grid of the dynatron valve V_2. By means of these impulses the valve characteristic is shifted and the valve is tripped. Across the choke-coil L, and dynatron, appear voltage waves of the form shown in Fig. 7(*a*), which are applied to the grid of a third valve V_3. The anode current (Fig. 7*b*)

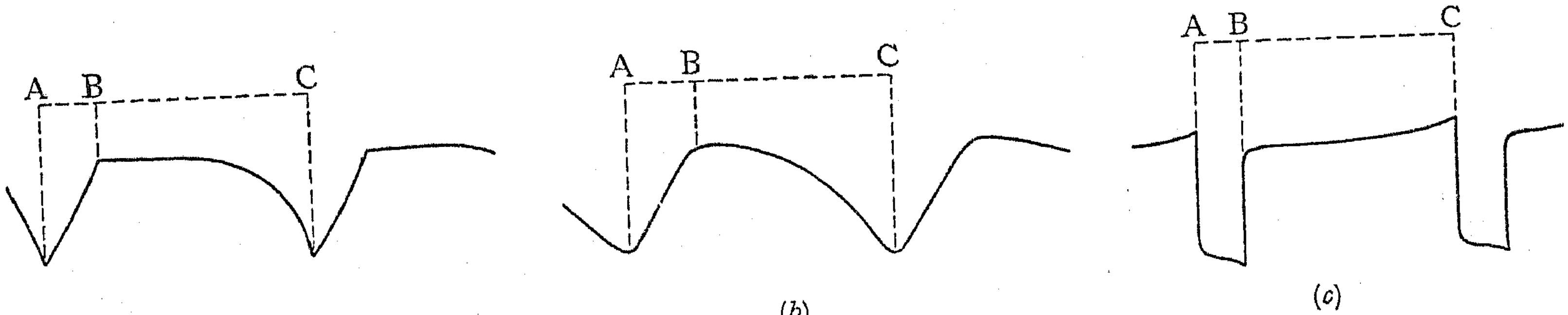

FIG. 7.—Periodic time-base equipment. Oscillograms of: (*a*) Voltage across L and dynatron. (*b*) Anode current of V_3. (*c*) Voltage on C and trap-plates.
AB = Writing period.
BC = Trapping period.

of V_3, of similar form to the grid voltage (Fig. 7*a*), flows in the deflection coils D, D, of the oscillograph, and the linear portion of this controls the time-base. Simultaneously a rectangular voltage-wave (Fig. 7*c*) is impressed on the condenser C and the trap plates of the oscillograph, in parallel with the dynatron valve. This is used during the positive half-waves for electrostatically trapping the return stroke of the time-base. The duration of operation of the beam trap is thus linked with that of the time-base.

This device prevents the return sweep of the beam from causing a trace on the screen, by direct trapping; not, as in most periodic time-base equipments, by giving the return sweep a much greater velocity than the writing sweep.

The frequency of the time-base can be altered in steps by varying the anode-circuit inductance L, and more finely by regulating the filament heating of the dynatron valve. The equipment gives a time-base which is approximately linear with respect to time. Since there is no sluggish gaseous discharge tube in the circuit, it can be used at frequencies 10 to 100 times higher than devices equipped with such tubes.

The impulse needed to actuate the device is only a few volts and is applied between grid and filament of the first valve. If this device is not tripped periodically, but merely once, it produces only a single sweep with coupled beam-trap. Fig 11(*a*), Plate 1, shows a 50-cycle wave recorded by a single sweep, which was initiated by an impulse of 10 volts. Thus in this periodic time-base equipment there is also a trip relay for a single-sweep time-base for uncontrolled events.

A method dispensing with an electrostatic beam-trap has been devised by the authors for use with this periodic time-base equipment. It employs an electromagnetic trap-coil energized by the anode current of a valve, the grid of which is supplied with the rectangular voltage-wave previously applied to the trap plates, as shown in Fig. 6B. The trap coil is placed on the discharge tube just before the anode aperture. In Plate 1, Fig. 12(*a*) shows an oscillogram of the same wave as Figs. 12(*b*), 12(*c*), and 12(*d*), but using electromagnetic instead of electrostatic trapping.

Electromagnetic Single-Sweep Time-Base Circuit.

The opinion has been expressed that a time-base written electromagnetically with deflection coils can never be so rapid as one written electrostatically. Considering the case where about 1 000 ampere-turns are required to produce a deflection of the full screen width, it is seen that the use of a small current will necessitate a large number of turns in the deflection coils, with consequent high inductance and low speed of beam sweep. If, however, large currents are used, the coils may consist of a few turns only, and the sweep may be made as rapid as desired. These conditions are obtained in the present

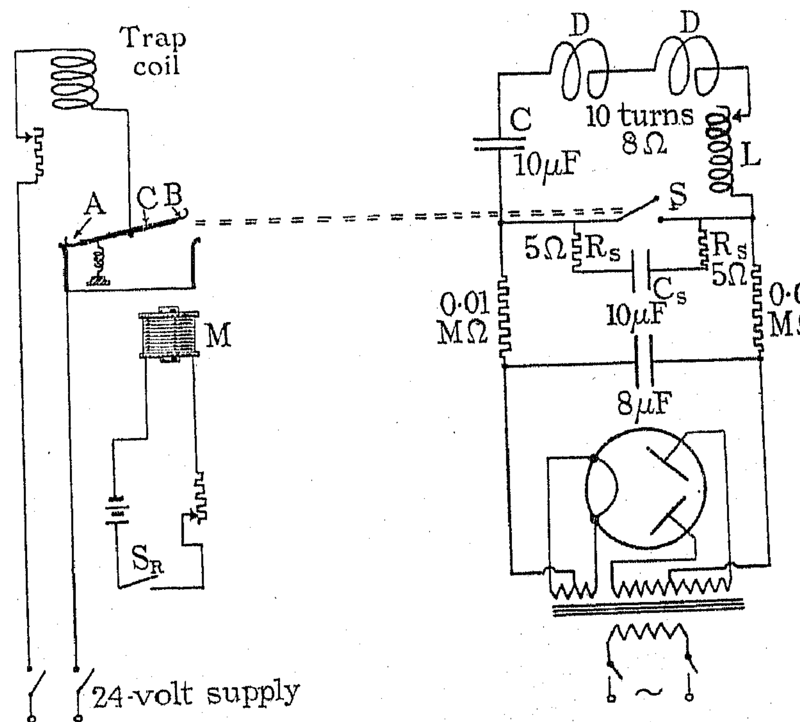

FIG. 8A.—Single-sweep time-base circuit with relay switch and electromagnetic beam-trap.

equipment by the use of a current of the order of 50 amperes produced by the discharge of a condenser through a resistance of a few ohms.

The circuit is shown in Fig. 8A. The condenser C is charged from the 400-volt rectifying equipment, and when the switch S is closed C is discharged through the deflection coils D, D, each of which is made of a few turns of resistance wire. The discharge is aperiodic, and the form of variation of current with respect to time

is shown in Fig. 8B. Since the deflection coils are mounted on glass only, at the screen end of the parallel portion of the tube, i.e. away from metal, no eddy currents are set up to affect the rate of change of the current. Previous writers* have mentioned the need for a sensibly uniform field when using magnetic deflection, and this is obtained by the use of plane coils of large area.

With the same components, slower sweeps may be obtained by the inclusion of extra inductance by means of the tapped coil L, so situated in the equipment that its field does not affect the cathode beam.

For describing the time-base, a portion of the first steep and approximately linear current-rise (Fig. 8B) is mostly used. This portion is selected, as described later, by means of an electromagnetic beam-trap. Selection of the slower fall in current can also be made if desired; or, alternatively, this portion may be used to describe a datum line on the oscillogram, provided that the phenomenon delineated by the current rise has reached a steady state by the time the beam sweeps back across the screen. Such a datum line is shown in the oscillograms

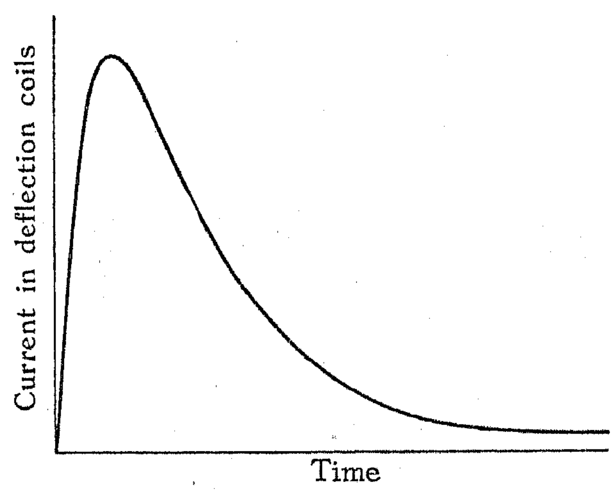

FIG. 8B.

of Fig. 9 (*a*, *b*), Plate 1; and Fig. 13(*a*, *c*), Plate 1. If, however, the beam is released only for the duration of the event, no datum line is recorded.

For certain purposes an oscillatory discharge might be used provided that a suitable portion was selected by means of the beam trap.

Many irregularities may be avoided by the use of a suitable " spark heating " circuit for the switch contacts, and this is obtained by the resistance and capacitance R_s, C_s (Fig. 8A).

Beam-Trap and Relay Switch.

The electromagnetic beam-trap consists of a small coil on the discharge tube just before the anode aperture. This position was found to give the most satisfactory trapping. The current through the coil is adjustable by means of a series resistance.

The initiation of the phenomenon to be observed, the beginning of time-sweeping, and the release and retrapping of the beam, are effected by a solenoid-operated switch as shown in Fig. 8A. When the switch S_R is closed, the electromagnet attracts an arm C which carries the movable portions of several pairs of adjustable contacts. The space relations of these contacts are adjusted so that the beam is released by the movable contact A leaving its corresponding fixed contact, and thus opening the trap circuit. Simultaneously the contacts S of the time-sweep circuit, which are also on the switch, are closed, thus starting the beam sweep.* After a suitable length of travel, contact B closes, retrapping the beam. An illustration of the consistency of operation of this switch is given in Fig. 9, Plate 1, where two oscillograms of a cable discharge wave show that in each case retrapping of the beam was effected at approximately the same

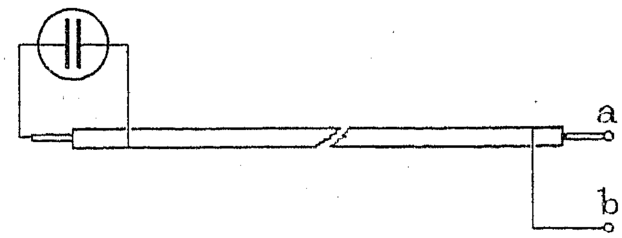

FIG. 8C.

instant, although several operations of the switch had been made in the time interval between the taking of these two photographs.

As an additional precaution to prevent fogging, the beam may be given an initial displacement off the screen by means of the unused pair of deflecting plates, by connecting them across the contacts of the switch S. When the potential between the plates is removed, by closing S, the spot jumps to the position on the screen from which time-sweeping commences. Since the time-constant of this local circuit is very small, the collapse of voltage is almost instantaneous. The oscillograms of Fig. 9, which were taken with this modification, show the absence of fog at the beginning of the trace, as compared with Fig. 13(*b*), Plate 1, where it was not employed.

This equipment is particularly convenient when the time-base and the phenomenon can be switched in with the same contact. Examples are given in Fig. 9 and Figs. 13(*b*) and 13(*c*), where cable discharge waves are shown. The circuit used is given in Fig. 8C. The points *a*, *b*, are connected across the contacts of the switch S. The charged cable is short-circuited on the closing of S,

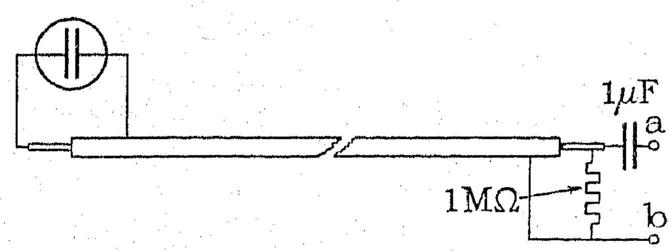

FIG. 8D.

and the variations of voltage at the farther end of the cable are applied to the oscillograph deflection plates. A similar circuit for cable charging waves is given in Fig. 8D, and an oscillogram so taken is shown in Fig. 13(*a*).

Electrostatic Single-Sweep Time-Base Circuit.

For uncontrolled transient phenomena an electrostatic deflection circuit is used for the time-base. Such an

* See Reference (17).

* One of the authors is at present engaged in investigating the application of electromagnetic time-sweeping and beam-trapping for uncontrolled transient recording.

equipment must: (*a*) Withhold the beam until the beginning of registration is desired. (*b*) Release the beam and commence time-sweeping concurrently with the arrival of the transient to be recorded. (*c*) Retrap the beam after a single sweep across the screen. Conditions (*a*) and (*c*) are necessary to avoid fogging of the screen before and after the sweep. The trapping and retrapping are effected by a suitable voltage applied to the trap plates of the oscillograph, as previously described. The sweep of the beam across the screen, constituting the time-base, is effected by connecting one or more pairs of deflecting plates across a condenser which is discharged through a spark-gap and resistance.

The sequence of these events, and their co-ordination

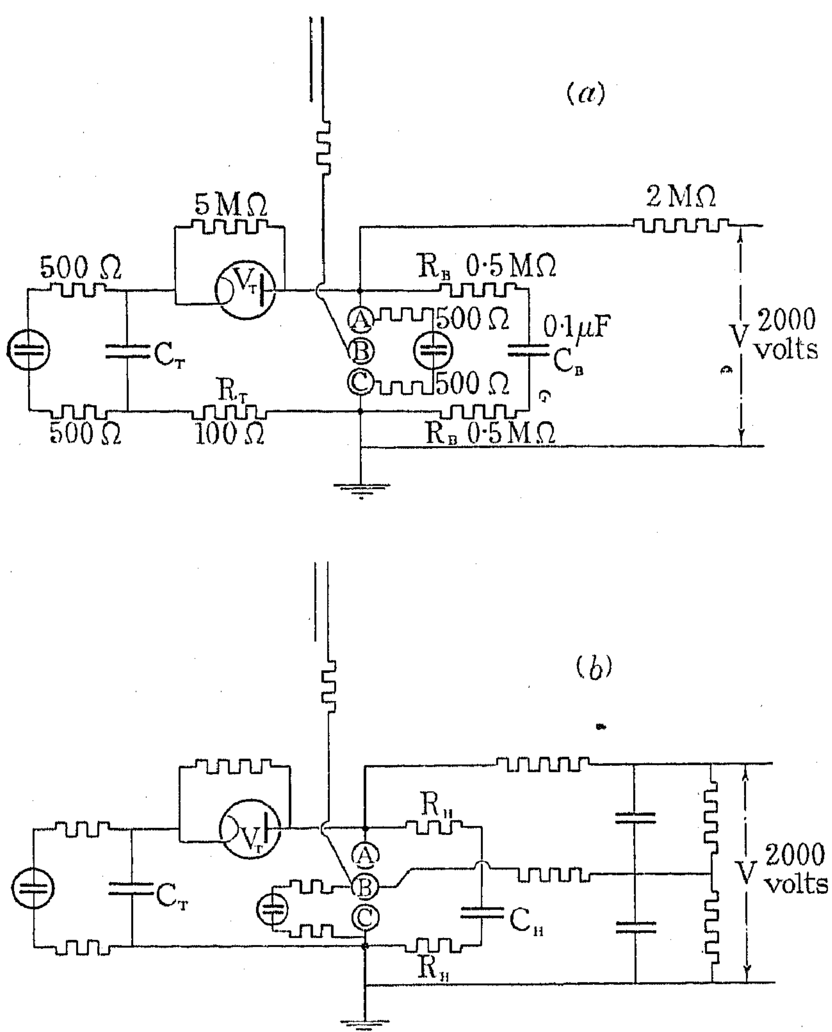

FIG. 10.—Single-sweep electrostatic time-base circuits.

with the time of occurrence of the phenomena, are controlled by the 3-electrode gap shown in Fig. 10. In Fig. 10(*a*), the "time" condenser C_T and the trap and deflection plates are all charged to a potential just insufficient to spark between spheres A and C. If the transient to be recorded is allowed to impress a small voltage impulse on a conductor connected to the middle sphere B, breakdown of the gaps A, B, and C occurs, the beam is released by the collapse of voltage on the trap plates, and time-sweeping commences as the result of the discharge of C_T.

For the present apparatus, the arrangement shown in Fig. 10(*b*) was first tried.* The time plates connected across the electrodes A and C were supplied at 2 000 volts, and the trap plates across A and B at 500 volts, by means of a capacitive potential-divider. Owing to the small time-constant of the trap-plate circuit the trap plates are rapidly recharged and the beam retrapped on the extinction of the spark. Spark heating is supplied by the capacitance C_H and resistance R_H.

Eventually the somewhat simpler arrangement shown in Fig. 10(*a*) was used. Here the trap plates are connected across A, C, and are thus maintained at the full voltage of the equipment. This device was found to give more complete trapping at a higher initial concentration of the beam. It was found necessary to make the time circuit approximately symmetrical to maintain good focus of the spot during the whole traverse. Since a saturated diode was used in the discharge circuit to produce a fairly linear time-base and to provide easy control of the time of sweep, by the adjustment of its filament current, a resistance R_T of similar value was inserted in the opposite side. Even at 2 000 volts, "bright" radio valves proved satisfactory for the valve V_T. Owing to the high reverse resistance of this valve, a shunting resistance is necessary for the recharging of C_T.

With the usual method of connecting the trap plates in parallel with the time circuit and using resistances in the discharge circuit, retrapping of the beam is hindered by the relatively slow rate of rise of voltage across the condenser C_T on recharge. In the present equipment a device was used to effect a more rapid retrapping of the beam. The circuit C_B R_B was arranged to have a large time-constant, so that on the extinction of the spark the voltage of C_B had not fallen appreciably and thus assisted the supply voltage to recharge the beam-trap plates. The constants used in this equipment are shown in Fig. 10(*a*).

As has already been stated, the initiation of time-sweeping at the desired moment is effected by impressing a voltage impulse on the centre electrode of the 3-electrode sphere-gap. This impulse is provided by the event to be recorded by making use of the capacitance of a coupling wire consisting of 0·25 to 0·5 metre of rubber-insulated twin cable. For low-voltage work the coupling conductor is connected directly to the transient-voltage source, and for high-voltage work it is connected to a short overhead wire placed in the field of the high-voltage impulse.

Steps must be taken to ensure that the time-base is already in operation before the wave to be measured reaches the deflection plates, if it is desired to record the beginning of the wave. When cable waves are being obtained at the far end of a cable this delay is already present by virtue of the length of the cable, but in other cases a delay cable must be introduced. Such a delay cable, in conjunction with a resistance potential-divider, was used to record the 160-kV wave produced by a Marx surge-generator (Fig. 14, Plate 1). It was found that 40 metres of cable provided the requisite delay without illumination of the spark-gaps by means of ultra-violet light.

SPECIMEN OSCILLOGRAMS ILLUSTRATING THE USE OF THE INSTRUMENT.

The oscillograms reproduced in Plate 1 were taken with the camera mounted as shown in Fig. 2, the trace on the screen being reduced to about half

* See Reference (14).

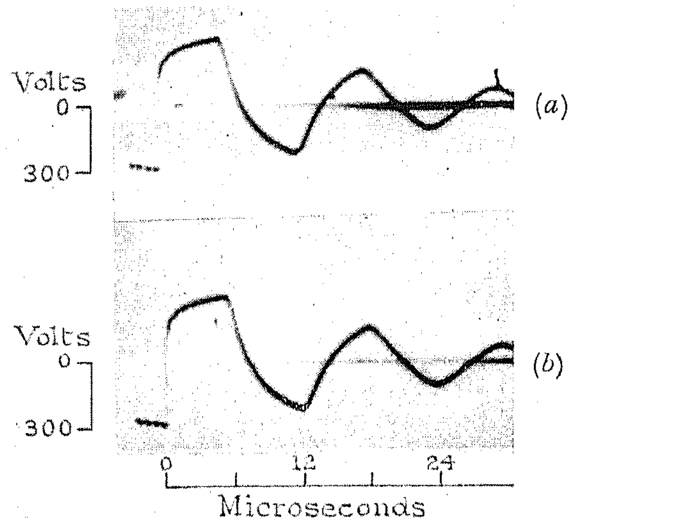

FIG. 9.—Oscillograms of 450-m cable discharge wave, using electromagnetic time-base and beam-trap with initial electrostatic displacement of beam.

(*b*) is a repetition of (*a*) after several intermediate operations of relay switch.

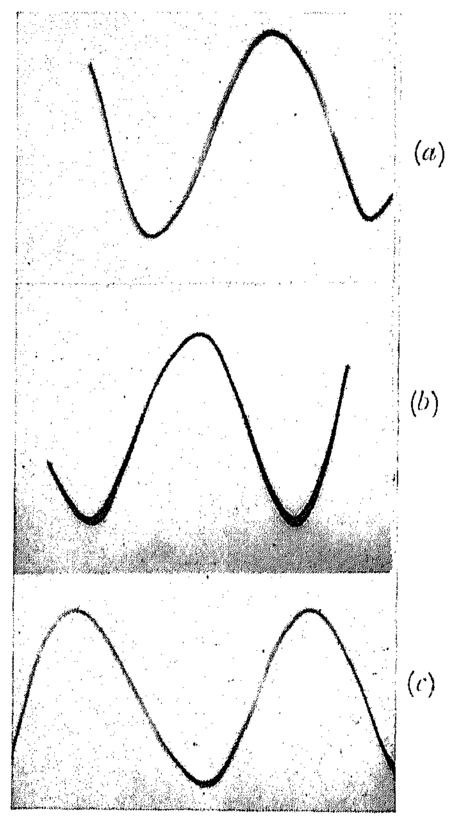

FIG. 11.—50-cycle mains voltage.

(*a*) Single traverse of time-base used for (*b*).
(*b*) With periodic time-base.
(*c*) Recorded with single-sweep electromagnetic deflection.

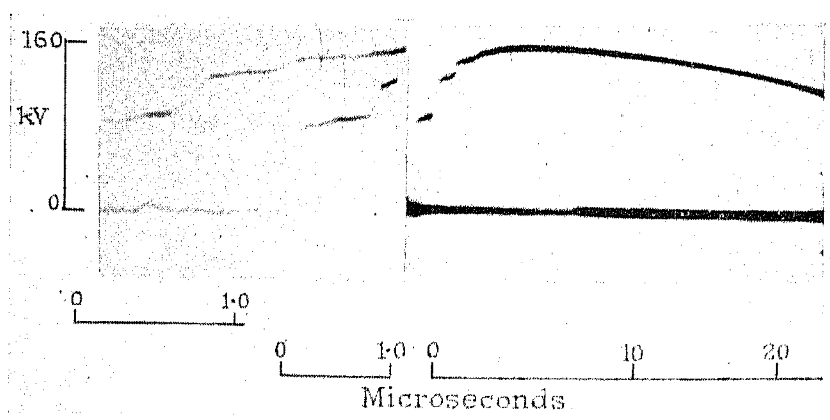

FIG. 14.—160-kV wave of impulse generator, using electrostatic time-base with different speeds of traverse to obtain wave-front and whole wave.

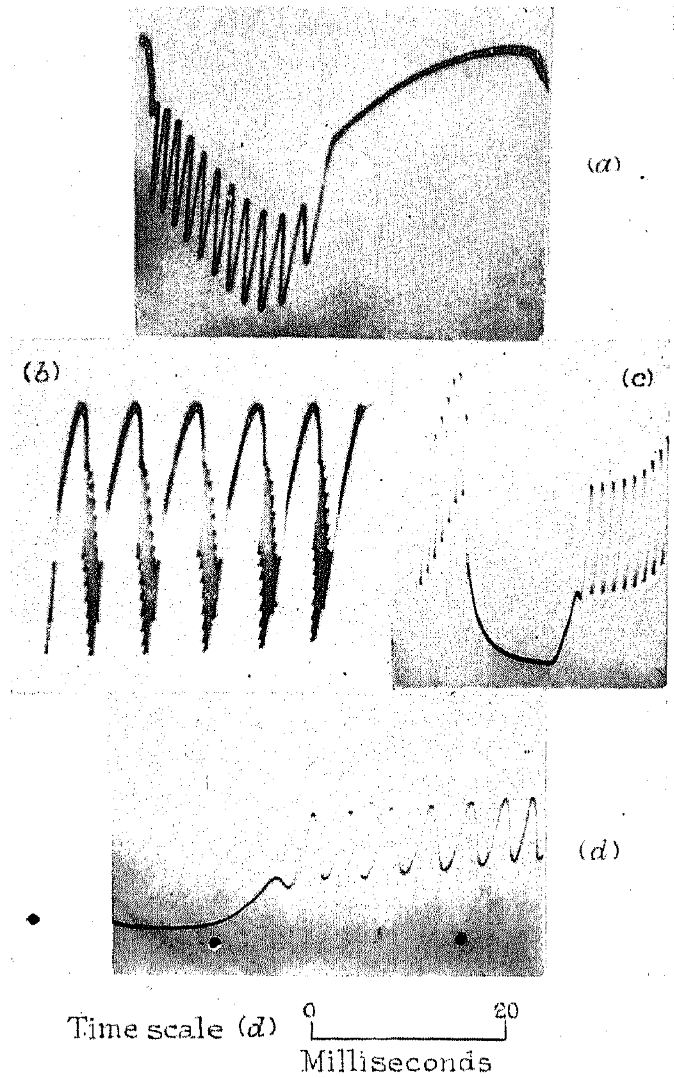

FIG. 12.—Oscillograms of 1 000-cycle wave with 25 000-cycle oscillation superimposed; all with periodic time-base.

(*a*) Electromagnetic trapping.
(*b*, *c*, *d*) Electrostatic trapping.

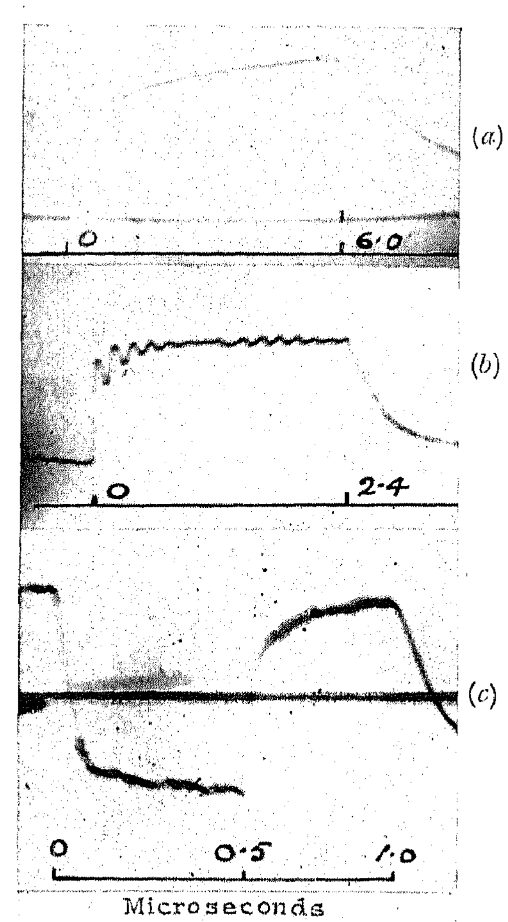

FIG. 13.—Cable waves recorded with electromagnetic time-base.

(*a*) Charging wave, 450-m cable.
(*b*) Discharging wave, 180-m cable.
(*c*) Discharging wave, 37·5-m cable.

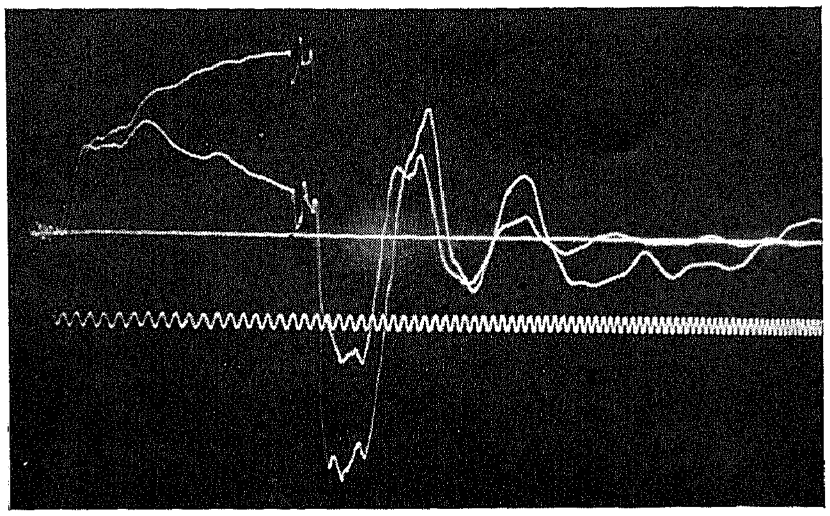

FIG. A. [See Dr. Miller's remarks (page 667).]
Frequency of time calibration oscillation = 5 000 000 cycles per sec.

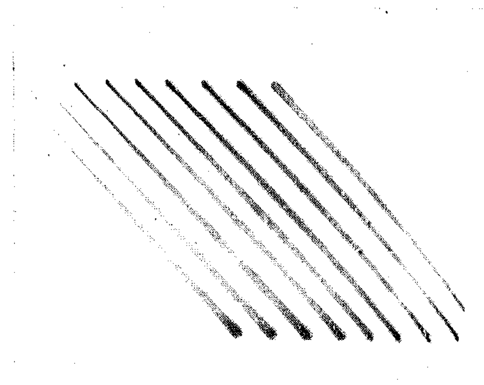

FIG. B.—0·8 ampere. [See Captain McGillewie's remarks (page 670).]

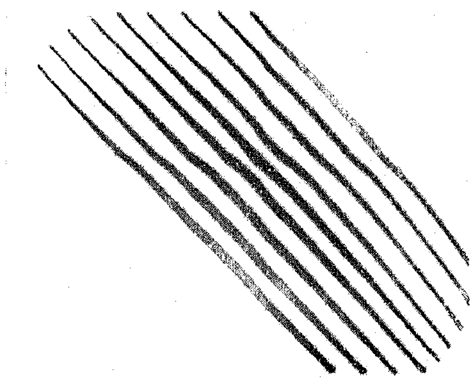

FIG. C.—0·9 ampere. [See Captain McGillewie's remarks (page 670).]

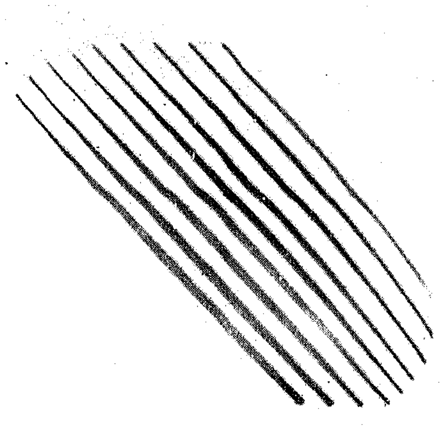

FIG. D.—0·95 ampere. [See Captain McGillewie's remarks (page 670).]

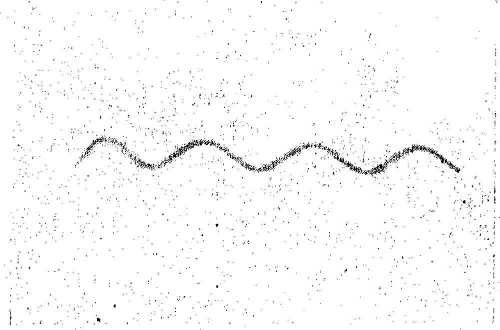

FIG. E.—230 kilocycles per sec. [See Captain McGillewie's remarks (page 670).]

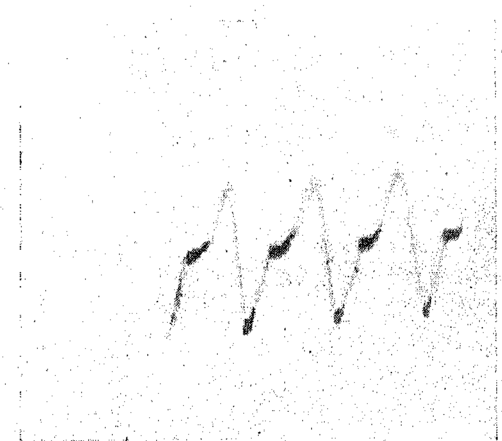

FIG. F.—230 kilocycles per sec. [See Captain McGillewie's remarks (page 670).]

size in the reproduction. The oscillograms are untouched.

The use of the periodic dynatron time-base equipment is shown in Plate 1 by (*b*), (*c*), and (*d*), Fig. 12, which represent waves of 1 000 cycles per sec., each having a superposed oscillation of about 25 000 cycles per sec., with successively faster time-bases. The fastest (Fig. 12*d*) indicates clearly the accuracy of the synchronization of the time-base and the fineness of the trace obtainable. Fig. 11(*b*), Plate 1, shows the 50-cycle mains voltage recorded with this equipment.

Owing to the great intensity of the spot, all phenomena may, if desired, be recorded with a single traverse of the time-base. Fig. 11(*c*) shows the mains voltage so recorded, using electromagnetic deflection. The change of current in the deflection coils is here obtained by the rise of current in a highly inductive circuit. These foregoing examples show that this instrument can deal successfully with many of the normal applications of the strip, and the low-voltage cathode-ray oscillographs.

The real domain of the instrument is the recording of high-speed phenomena, such as transients. Fig. 13(*a*), Plate 1, shows the first half-cycle of a charging wave on a 450-m cable, whilst a discharging wave with superposed oscillations on a 180-m cable is shown in Fig. 13(*b*). Fig. 13(*c*) shows a similar wave on a 37·5-m cable; the period of this wave is 1 microsecond. If we assume the first linear rise to occur in 5×10^{-8} sec., this represents a writing speed of more than 300 km per sec. on the fluorescent screen. All these three oscillograms were taken with the electromagnetic single-sweep time-base circuit, using the circuits shown in Figs. 8C or 8D.

As an example of the recording of uncontrolled phenomena, using the electrostatic, single-sweep time-base, Fig. 14 (Plate 1) shows a 160-kV wave from an impulse generator, using a resistance potential-divider. This was taken with different speeds of traverse of the beam, to record both the wave-front and part of the tail of the wave.

Up to the present the cold-cathode oscillograph has been continuously modified and improved,* and it has now reached a stage such that for many purposes a standard instrument can be envisaged. It is hoped that the simple sealed-glass tube described in this paper represents a contribution in this direction.

* The work of Rogowski and his associates with low-voltage cold-cathode tubes, with and without additional accelerating voltages, may be mentioned as a recent example (see Reference 20).

The authors gratefully acknowledge their indebtedness to Prof. W. Rogowski and his co-workers at Aachen, whose extensive researches on different aspects of cathode-ray oscillography have in a large degree made possible the present equipment.

This paper was written, and the work carried out, in the Electrical Engineering Department of the Royal Technical College, Glasgow.

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[The discussion on this paper will be found on page 666.]

DISCUSSION BEFORE THE METER AND INSTRUMENT SECTION, 4TH JANUARY, 1935, ON THE PAPERS BY PROF. MACGREGOR-MORRIS AND MR. HENLEY (SEE VOL. 75, PAGE 487), AND PROF. PARKER SMITH, DR. SZEGHÖ, AND MR. BRADSHAW (SEE VOL. 76, PAGE 656), RESPECTIVELY.

Dr. J. L. Miller: I have noticed the greater attendance which has characterized each successive meeting of the Institution when a paper on oscillography has been read, and this, in my opinion, indicates in no uncertain manner the widening interest shown in these instruments and their importance in electrical measurements of all kinds. Now that we have various types of cathode-ray oscillographs, from the point of view of life, stability, sensitivity, and visibility of trace, working very well in their respective voltage and frequency ranges, I think the next logical step forward is to obtain a better understanding of all the factors that contribute to distortion, so that we may make more accurate voltage measurements of short-time and high-frequency phenomena. Fortunately, the continuously evacuated oscillograph is free from those troubles, such as origin distortion, loss of focus of the spot at high recording speeds, and non-linearity of the voltage deflection, which are associated with the small sealed-off oscillograph with gas focusing; and therefore, from the point of view of ability to record faithfully, there is scope for improvement in the latter instruments.

The paper by Prof. MacGregor-Morris and Mr. Henley is a noteworthy contribution in this direction, because it gives us information which will eventually either show us how distortion in these small tubes may be controlled and taken care of accurately by calibration, or, alternatively, if this is impossible, tell us that we must not expect too much from them. In such a case, I suppose greater use will be made of the new electrostatically-focused sealed-off instruments. Further, in view of the fact that the small sealed-off oscillographs are supplanting the Duddell oscillographs to an ever greater extent, the work carried out by Prof. MacGregor-Morris and Mr. Henley is of interest not only to the specialist but also to many engineers interested in power-frequency problems.

The paper by Prof. Parker Smith, Dr. Szeghö, and Mr. Bradshaw is a very interesting one because it describes a new form of high-speed oscillograph. There are obviously great difficulties in getting such an instrument to operate well, and therefore any remarks that can be made on the details of construction can only be remarks of commendation. The comments I am going to make, therefore, are of a general character and are put forward rather from the viewpoint of a transmission and transformer engineer who uses oscillographs, than from the point of view of an instrument designer.

Now the sealed-off oscillograph is less adaptable than the continuously evacuated one. One cannot, for instance, without very considerable difficulty, vary the deflection-plate sensitivity by altering the plate separations. In addition, the instrument is less robust; the continuously evacuated oscillograph, being made of metal, cannot be easily damaged, and if it is it can be repaired immediately by the laboratory staff.

Apart from these considerations, the main difference, of course, between the continuously evacuated oscillograph and the sealed-off oscillograph is that the latter requires no pumps and is always ready for use and photography. Therefore, the three points which must be considered are, firstly, the financial aspect of sealing off and eliminating pumps; secondly, the operating value that can be placed on this elimination of the pumps; and thirdly, the disadvantages when a glass sealed-off construction is employed. Beyond these there are no other important differences and the circuits described later in the paper are equally applicable to both types.

Regarding the financial question, the true comparison should be the cost of a continuously evacuated oscillograph plus its pumps against the cost of the sealed-off type plus the external camera plus an allowance to cover depreciation occasioned by the burning-up of the tube; the cost of external circuits is precisely the same for both tubes. Therefore, in order to make this comparison, I should like the authors to give us the cost of a tube and the camera, together with their experiences of the average life. The life is an important question since in our own case the cathode is burning from 2 to 5 hours per day, so that, in the case of a sealed-off tube, assuming a life of 1 000 hours, replacement would be necessary after a time not greater than about 9 months. In addition, spares would have to be carried, and there is always the danger that, owing to a particular replacer tube failing almost immediately on being put into service, the laboratory might find itself without any means of taking oscillograms. In general, of course, the average laboratory does not want to lock up the capital represented by a relatively large number of spares.

Regarding the operating value that can be placed on the lack of pumps, I would firstly point out that a mercury pump backed by an oil pump is an extremely reliable equipment. It never goes wrong, and, except for changing the oil in the backing pump, replenishing the P_2O_5 (and this does not matter very much), and occasionally ensuring that there is adequate mercury in the other pump (again, it is not necessary to be very exact here), the equipment requires no maintenance. With normal oscillographs no liquid air is required, of course. It is therefore difficult to see that the pumping-out of an oscillograph presents any difficulty, and rarely have we been held up while waiting for the vacuum to be attained. Plates have to be developed, and during this time a fresh batch can be inserted and evacuated. Evacuation only takes a few minutes, even when a large holder containing, say, 24 plates, is inside. (In this connection it is worth while mentioning that plates have a decided advantage over films for most purposes, since with plates any number from one to the full complement may be taken out and developed, whereas with films, if only one record is required, say, the rest of the roll must either be wasted or examination must be deferred until the whole roll has been exposed; when one realizes that an oscillograph may use £3 to £4 worth of photographic material per week, such considerations are worth bearing in mind.) Without taking into account

the flexibility which results from having the vacuum completely under control, it would seem, then, that the elimination of the pumps offers little advantage; and it is notable that workers in the X-ray and radio-valve fields are not hesitating nowadays to employ continuously evacuated equipment.

Regarding the disadvantages which arise when a sealed-off construction is employed, there are two main difficulties actually mentioned in the paper (page 661). The first is that the concentrated spot may not rest on the screen for more than a fraction of a second. Apparently, if this occurs, the fluorescent material is badly burnt, and if the time is prolonged the glass may be pierced. I feel that this is a real disadvantage, since a broken connection in one of the auxiliary circuits might easily allow the beam to rest on the screen. Further, carelessness in handling—and nowadays the beginner in the laboratory is called upon to do the routine handling of the equipment—would give the same result, and I can well visualize a laboratory being put to considerable expense on this account. The second difficulty is that the authors state that there is some distortion when recording photographically; it would therefore be well to have their opinion on the amount of this distortion. Possibly it is negligible, but it must be remembered that during the past 2 or 3 years most workers in high-speed oscillography have been striving after greater accuracy of transient-voltage measurement, so that to-day we may state that these measurements can generally be made with an error not exceeding $\pm 1\cdot 5$ per cent—in such cases a thin trace is necessary, and Fig. A (Plate 2, facing page 665) shows a beautiful example of the fineness of trace that can be achieved with the continuously evacuated oscillograph—and therefore the use of any apparatus, however novel, which may make it impossible to attain this accuracy, is a retrograde step. I realize that the two points just discussed are referred to in a footnote on page 661, but I should like to know why the improvements suggested therein are not incorporated in every tube, excepting those used for demonstration purposes. In this connection I should also like to know whether the apparatus actuating the movable screens is liable to give any trouble. Presumably if this got out of order it would mean the scrapping of the tube.

Information regarding the limiting factor in the life of the tube would be valuable. Is it inability to find a satisfactory spot on the cathode, eventual failure of the vacuum, or deposits on the glass surface? I should also be interested to know whether the tubes are suitable for continuous burning of the cathode, to enable them to measure lightning transients on an overhead line. The authors refer to a discharge between deflection plates under certain conditions, and they also state that a leakage resistance of 10^8 ohms was measured between them. Presumably this measurement was made with the cathode unenergized, and I should like to know whether they find any appreciable decrease in this resistance when the normal beam current is flowing. Our own oscillograph shows infinity on a Megger connected between plates, with the beam on, but it is possible that the authors' oscillograph would show a lower reading owing to the greater gas pressure. It is a point of importance, of course, when making certain types of measurements, and a leakage resistance of $20\,\mathrm{M}\Omega$, even, may give rise to trouble. It is also interesting to note how the pre-anode focusing current controls the discharge current. Fundamentally the same effect occurs in our own discharge tube, which is electrostatically focused. By control of the potential of the cathode shield, the character of the discharge is altered completely. I should further like to know whether the authors' tube has a linear voltage deflection and whether any distortion arises from the fact that the electromagnetic bias coils are mounted in the same plane as the deflecting plates; we always prefer to mount such coils before the electrostatic deflection takes place.

A development in the future may be the general use of an oscillograph having several independent beams all impinging on the same screen, so that several quantities may be measured simultaneously. This has already been done by Knoll,* but it must be remembered that his system required a divergent pre-anode beam and four anode apertures. I should like to know, therefore, whether the sealed-off high-speed oscillograph, which in the present state of the art requires the beam to be brought to a fine point on the anode by means of pre-anode electromagnetic focusing, lends itself so readily to an application of this sort.

I have so far criticized the sealed-off oscillograph on the scores of distortion, lack of robustness and adaptability, and possibly excessive maintenance charges. In addition to this, of course, it is apparently not yet capable of achieving the highest writing speeds attained by the continuously evacuated oscillograph with the photographic plates inside the vacuum, and this fact is of importance in many experiments. For instance, it would be difficult to delineate by means of the sealed-off oscillograph the high-frequency oscillations superimposed on the fronts of surges when these fronts were very steep, and it would probably be impossible to examine phenomena in the fraction of a microsecond immediately preceding voltage flash-over. Such experiments are, however, only carried out by a few, and I quite agree that for a large number of surge experiments the recording speed of the tube is sufficiently high; in fact, I must confess that I was amazed at the visual sensitivity on fairly fast phenomena shown during the demonstration.

One can level no criticism against the incorporation and lay-out of the various circuits and supplies, because everything that is wanted for recording oscillations over an extremely wide range of frequencies, or transients, both controlled and uncontrolled, is built into a very compact space. The arrangement is similar in principle to our own, except that we segregate the cathode H.T. supply, the control switches, and the transient equipment,† the latter being mounted with the oscillograph. This enables us to employ short leads to the time-sweep and trap plates, just as in the authors' case.

There are many interesting features in the auxiliary circuits, and I think particular attention should be drawn to the very valuable idea of retrapping the beam during the rapid return sweep when recording repeated phenomena. It is a device that might well be copied, by incorporating an auxiliary set of trap plates and a

* M. KNOLL: "The Multiple Cathode-Ray Oscillograph," *Elektrotechnische Zeitschrift*, 1932, vol. 53, p. 1101.

† J. L. MILLER and J. E. L. ROBINSON: *Journal I.E.E.*, 1934, vol. 74, p. 511.

diaphragm, in the low-voltage sealed-off oscillographs. I also note with interest that the authors are in agreement with us on the advantages of symmetrically arranged time-sweep circuits—a point which was criticized when Mr. Robinson and I read our paper.

While I feel, therefore, that the tube itself has certain disadvantages, the equipment as a whole is extraordinarily adaptable and has a wide application in the measurement of all types of short-time phenomena.

Mr. William Wilson: Engineers have grown accustomed to recognize cathode-ray oscillograms by their extremely fuzzy and badly fogged appearance. The authors of both the papers show that this is no longer true when modern apparatus is being used. There is no doubt that the cathode-ray oscillograph is developing very rapidly and is about to have a widely extended use for testing purposes, even in connection with heavy industries. I agree with Dr. Miller's remarks in this respect.

There are already three purposes for which such oscillographs are employed in connection with the design and testing of power engineering apparatus, with which I am associated. First, in the testing of mercury-arc rectifiers, a gas-focused tube is employed for exploring the wave-form and is instrumental in the examination of ripples and arc drops. For such a purpose the simple form of tube is very suitable; but the other two purposes are more exacting. One of these is for the measurement of impulse voltages and lightning transients, which is becoming more and more necessary in connection with the testing of high-tension apparatus, and which requires oscillograms for registering to within 1 microsecond. For that work it had been my impression, until I read the paper by Prof. Parker Smith, Dr. Szeghö, and Mr. Bradshaw, that the metal-tube type of oscillograph with continuous evacuation was essential. It seems, however, as though the glass-tube pattern should also be available for this purpose, for Fig. 13(*c*) records almost a full cycle in the space of only 1 microsecond, and it is quite a clear and definite trace. The third purpose is one for which I think the metal-tube pattern must be used, namely, the testing of oil switches and other circuit-breaking equipment. For this, 10 to 15 microseconds is about the minimum period that will have to be resolved. It will be necessary, for example, to be able to distinguish waves of about 100 kilocycles per sec. The chief difficulty in this case is that the record requires a travelling film moving at the rate of about 4 miles per minute, introducing difficulties in connection with sensitivity. If the glass-tube instrument were employed, the film would have to be outside the vacuum, and the record be obtained by photographing the image on the fluorescent screen as described in the paper. Since this would sacrifice a great amount of sensitivity, it seems to me that the metal-tube pattern is practically essential for such work, in spite of its bulk and expense. The importance of using a suitable cathode-ray oscillograph for this purpose is that the act of circuit-breaking depends upon the rate at which the restriking voltage rises during the zero-pause of current, and the only method of ascertaining the real performance of the breaker is to obtain an accurate trace of the voltage fluctuating at the natural frequency of the test circuit. I have some records taken recently with such an apparatus, showing a wave of 100 to 200 kilocycles per sec., and they are not merely as good as oscillograms taken with the ordinary mechanical instrument but are in fact much better, being the most perfect that I have ever seen. They show not the slightest trace of fog, and the focusing of the spot is extremely sharp. Calculations of the greatest exactitude could be made by means of such records as these.

Previous speakers have compared the two types of oscillographs, and I should like to state my views as to their relative advantages. In the first place, the metal-tube pattern is undoubtedly much more sensitive than the other. The records just mentioned were taken with a film having a speed of only 20 H. and D., whereas a speed of about 4 400 H. and D. is in common use for ordinary photography. Hence there is still a great deal in hand in the former case, rendering a very much higher writing speed actually available than is used at present. Secondly, there is the absence of fog and the extremely sharp definition given by the metal-tube type, which does not seem to be obtainable with any other type of instrument. Thirdly, its robustness and durability are outstanding. Prof. Parker Smith has mentioned the comparatively short life of the glass-tube type, and I should like to ask whether these tubes cannot be repaired. As they cost as much as £40, one would imagine that it would pay to do so. Finally, there is no after-glow when the fluorescent screen is eliminated. A "memory" is undoubtedly an advantage when one is making a single measurement, but it must be somewhat of a drawback when one is using a rotating drum or a moving plate, since it must cause some fogging.

As regards the glass-tube pattern, the absence of pumping equipment confers a valuable advantage from the point of view of cheapness; while, in the second place, the apparatus is portable and therefore the one unit can be used for a number of different purposes. The metal-tube instrument to which I have just referred weighs over 2 tons and is about 8 ft. tall. It is a particularly fine model, but is a fixture, and in this respect is at a disadvantage. I do not, however, regard the time and the trouble of evacuation as important. One does not make a test with an apparatus such as this more often than about once in half an hour, and something like 12 minutes is sufficient for evacuation, which is an automatic process and constitutes no particular drawback.

There are two questions which I should like to ask in connection with the second paper. The authors mention that the tube is hydrogen-filled at a pressure of 5×10^{-2} mm of mercury; I do not see the advantage of that large amount of gas. The tube is not of the gas-focusing type, since a concentrating coil is fitted; but with all that gas present there must be a certain amount of gas-focusing going on, which would be expected to cause loss of definition at high frequencies. The record in Fig. 13(*c*), to which I have already referred, is less well-defined than the others, and I should like to ask whether the lack of definition is not due to this cause. With the continuously evacuated pattern, moreover, it is possible to regulate the pressure at the optimum value for each part of the tube. With regard to the two coils for neutralizing the earth's field, could not the same

end be obtained more simply by effective screening? It seems to me that, although the earth's field can be countered in the way shown, other and stronger fields due to the test that is being recorded cannot be so compensated, since the flux produced is variable, and there may be additional fluxes due to other apparatus in the vicinity. In a high-power test on a large oil switch, to take an extreme case, the magnetic effect of the circuit-breaking must extend for a long distance from the actual circuit, and only screening would be able to obviate interference due to this cause.

Mr. V. A. Hughes: Since Prof. MacGregor-Morris and Mr. Henley prepared their paper I have had the opportunity of making further investigations at Queen Mary College which have shown that the supposed difference between the practical and theoretical sensitivities is almost entirely due to insufficient allowance for the fringing of the electrostatic field at the ends of the deflector plates.

The authors had suggested that this difference was due to the potential of the fluorescent screen (vol. 75, page 490), and to test this an oscillograph was constructed with the fluorescent material deposited on the conducting surface. The screen potential was found to be 60–70 volts below that of the anode, and was larger for smaller beam currents and almost independent of the anode voltage.

As the fluorescent material has a very high resistance the only way an appreciable current can flow from the fluorescent spot to the conducting surface is by electrons passing through small holes in the fluorescent material and travelling through the gas to any portions of the silvering that are not covered with fluorescent material. This makes it impossible to measure accurately the potential of the fluorescent spot when there is any current flowing from it to the silvering. An estimate of the potential difference can, however, be obtained from the curve of screen potential plotted against screen current. When allowance has been made for this, the effect of the potential of the fluorescent spot is much less than that predicted by the formula on page 490. The explanation for this is, I believe, that only the fluorescent spot acquires the full negative potential and the remainder of the screen acquires an intermediate potential. In this case the equipotential planes will be approximately perpendicular to the path of the beam, and not to the axis of the tube as the authors assume for their calculations.

The measurements made indicate that a screen (or fluorescent spot) potential of 60 volts below the anode did not produce more than 1·5 per cent increase in sensitivity with an anode voltage of 400 volts.

On page 488 the authors apply a correction of 6 per cent for the fringing. This, I believe, is inadequate, and calculations of the field distribution on the lines suggested by Sir James Jeans in his "Theory of Electricity" show that it should be between 20 and 30 per cent. With plates 14 mm long and 5 mm apart, the fringing at each end will account for an additional 20 per cent deflection, provided that there are no other bodies in the neighbourhood. If the anode is 5 mm away from one end, the correction is reduced to 10 per cent for that end. As all the tests were made with one pair of plates earthed, their effect on the other pair will be similar to that of another anode. The total correction for the pair nearer the anode will be an addition of 20 per cent. The diaphragm after the second pair of plates makes it impossible to estimate the correction, except to say that it will be between 20 and 30 per cent.

Sensitivity measurements made on two oscillographs gave the ratio of the practical sensitivity to that calculated by the simple formula as 1·30 for the x plates (nearer the screen) and 1·25 and 1·30 for the y plates (nearer the anode). It would appear that the fringing does not quite account for the difference; but calculations were made for the dimensions given in Fig. 1, while the dimensions of the tubes used varied by as much as 20 per cent. This will mean that the fringing correction will be 2–3 per cent in error in some cases.

As an additional check, the magnetic deflections were measured, and were found to agree with those calculated from the simple formula within the experimental error of 3 per cent.

Captain D. I. McGillewie: Some tests which I carried out on an experimental type of tube appear to confirm the theory put forward by the authors of the first paper. The tube in question was of Standard Telephones and Cables manufacture and similar in all respects to their 4018-A type, with the exception that the interior of the bulb, between the anode and the screen, was coated with a conductive material, a connection to which was taken out through the side of the bulb. When this coating was connected to the anode it was found that the sensitivity was reduced to about 85 per cent of its normal value, indicating that by the provision of an alternating path for the secondary electrons the retarding field had been reduced. When the conductive coating was made positive relative to the anode, a further reduction in sensitivity was observed, whereas a negative potential gave a proportional increase. Actually, 260 volts on the anode with the coating strapped to it gave a sensitivity corresponding to 300 volts on the anode of a standard tube; a positive potential of 60 volts on the coating gave a sensitivity corresponding to 320 volts, whereas a negative potential of 60 volts gave a sensitivity corresponding to 280 volts.

Another interesting feature was observed, namely, that whereas with the standard tube the sensitivities of the two pairs of deflector plates are approximately equal, although one pair is farther from the screen, when a negative potential was put on the conductive coating of the experimental tube the plates nearest the anode became less and less sensitive relative to the other pair as this negative voltage was increased. This appears to indicate very definitely that the velocity of the electrons is changing during the passage between the anode and the screen, but that the difference in sensitivity of the two pairs of plates caused by this change is, in the standard tube, approximately balanced by their different distances from the screen.

There is one more point to be noted, namely, that although it was possible for the experimental tube to be operated at a lower anode voltage, there was, as will be obvious from my previous remarks, no actual gain in the maximum possible sensitivity.

Referring now to the question of the variation of origin distortion with gas pressure, it is possible to obtain

similar results to those shown in Figs. 13 and 15 of the paper by Prof. MacGregor-Morris and Mr. Henley, with an argon-filled tube by simply varying the filament current. Fig. B (Plate 2, facing page 665) shows the almost complete lack of origin distortion with a filament current of 0·8 amp. Figs. C and D show the origin distortion with filament currents of 0·9 and 0·95 amp. respectively. These records were all taken with the Standard Telephones and Cables 4018-AB tube, which employs a positive voltage on the focusing cylinder.

In Section 4(*b*) the authors state that the variation of sensitivity will vary also with the molecular weight of the focusing gas. This would appear to involve a greater reduction of sensitivity with argon than with helium, a deduction which does not appear to be borne out by Figs. 10A and 10B. Perhaps this point can be explained by the authors.

With regard to Section (5), whereas in the Summary reference is made to the dependence of gas focusing on the transverse speed, in the text the authors refer almost exclusively to the effects of deflecting frequency. My experience has been that what really matters is the "writing speed." If one attempts to record single linear traverses across the screen, the focus has definitely to be altered as the transverse speed (which in this case is the "writing speed") is increased. If, in addition to the transverse linear velocity, we apply an alternating vertical velocity, the writing speed will no longer be constant and the difference between the maximum and minimum writing speeds will depend upon the amplitude of the alternating wave and the distance between the peaks of successive waves. I have found that as long as the difference between the maximum and minimum writing speeds is not too great a very good focus can be obtained of the whole trace at frequencies up to 250 kilocycles per sec. at least, and probably much higher. This is shown in Fig. E.

In the extreme case, e.g. Figs. 17 to 24 of the paper by Prof. MacGregor-Morris and Mr. Henley, when a single line is traced out by an alternating voltage of high frequency and fairly large amplitude, there is a very great difference between the maximum and minimum writing speeds, and therefore it is quite impossible for both the ends and the centre of the trace to be in good focus. This may account, to some extent, for the peculiar shape of some of the curves in Figs. 3 to 9, as records which I have obtained up to 250 kilocycles per sec. show no origin distortion (see Fig. F).

Some of the previous speakers have referred somewhat slightingly to the capabilities of the low-voltage gas-focused cathode-ray tube. It may be of interest to state that it has been found possible to record, without fogging or other objectional features, a single traverse of a 230-kilocycle wave at a maximum writing speed of approximately 26 km per sec. This is shown in Fig. F.

Mr. A. K. Nuttall: I propose to confine my remarks mainly to the paper by Prof. Parker Smith, Dr. Szeghö, and Mr. Bradshaw. The sealed-off high-speed tube which it describes is of particular interest, in that as far as I know it is the first tube of its type to be used in this country. I want to associate myself with Dr. Miller's remarks on the subject of the continuously evacuated tube. This is not, as is frequently supposed, a clumsy and difficult piece of apparatus to handle. Mechanical pumps now manufactured in this country have great speed and a very low ultimate pressure, and the oil diffusion pump is a very robust and reliable device. With regard to the rotating cathode described in Prof. Parker Smith's paper, I should like to know whether the authors can give any estimate as to how often and how far one has to shift this cathode, and consequently how long one may expect it to last. One remarkable point about the oscillograms shown is the absence of what are known as "retrograde rays." One rather expects to find these if the discharge tube is not inclined to the axis of the main tube, and I should like to ask the authors whether the absence of these retrograde rays, which are generally accepted as being caused by particles which have lost their charge but not their velocity, is due to collisions by these particles with gas molecules in the tube.

The electromagnetic beam-trapping and time-base circuits are extremely ingenious, and I think the consistency with which these records can be reproduced is remarkable; but it is fair to point out that for single-transient work the accepted electrostatic methods of trapping and time-sweeping are perfectly adequate. I notice that the authors employ two pairs of beam-trap plates. A similar arrangement was used by Gábor, except that he used two pairs cross-connected in order to get rid of the effects of residual oscillations in the beam-trap circuit, or oscillations picked up by that circuit from circuits outside. The present arrangement would seem to be conducive to oscillations in this circuit, and I should like to know whether the authors have any evidence of such oscillations taking place. The focusing shown by the records given in the paper is remarkable, in view of the fact that the tube is gas-filled and one may expect to obtain collisions after the period when the beam has passed through the second focusing coil. In view of the fact that the spot on the screen is so intense and liable to damage the screen and very shortly puncture the glass, I should like to ask the authors how they focus their beam on the fluorescent screen.

The resistance between the deflection plates is given as greater than 10^8 ohms at 500 volts; one would expect that resistance to go down as the voltage applied increased. Have the authors made any measurements at higher voltages than that, say 2 500 volts, particularly both with the beam on and with the beam off? The oscillograms show a maximum voltage of about 300 volts. It might be preferable for this sensitivity to be decreased slightly. There are certain phenomena connected with spark discharges which are more conveniently obtained with voltages in excess of 2 000 volts; and, although one may use potential dividers, usually in small circuits with small spark-gaps the presence of a potential divider is liable to upset the circuit conditions. Hence it would seem at first sight to be preferable to use plates of rather lower sensitivity.

The writing speed achieved is very high in view of the facts that this is a gas-filled tube, external photography is being used, and there is no cooling of the discharge tube. Although the speed is high, laboratory work frequently requires speeds a great deal higher than this. For example, I very much doubt whether this

tube would be able to record the natural frequency of the loop comprising the deflector plates and the tube itself; and there are many other phenomena—such as oscillations superimposed on a steep-fronted impulse wave, or vacuum arc oscillations—which require a higher writing speed than this and necessitate the use, at present in any case, of the continuously evacuated hard tube.

Dr. Miller referred to the necessity of an oscillograph which is capable of recording more than one variable at once. It is interesting in this connection to point out that Mr. Whelpton has recently developed a continuously evacuated tube capable of making three separate records simultaneously on a film which rotates on a drum. This apparatus will spread out a 50-cycle wave over about 3 ft. of film, and can record frequencies up to about 100 000 cycles per sec. It is, of course, particularly applicable to switchgear testing work. The continuously evacuated tube has one other application, however. In the laboratory where Mr. Whelpton's tube was produced we are developing a continuously evacuated tube in which we hope to be able to dispense with the potential divider, and to which we can apply a voltage up to 100 kV to earth, direct on the deflector plates. With this tube we hope to be able first of all to check the existing potential-divider methods which we know to be theoretically sound but on which it would be interesting to have an absolute check, and also to provide an instrument of very high impedance which will produce very small disturbance in the circuits in which it is placed.

Mr. L. H. Bedford: Referring to the paper by Prof. MacGregor-Morris and Mr. Henley, I am delighted to find that Mr. Hughes has resolved what seemed to be a serious anomaly with regard to the observed sensitivity. The theory given in the paper, namely a very high negative voltage on the screen, is extremely ingenious, but seems unacceptable on various grounds. One of them is that we have evidence of what the potential on the screen really is, and we find in practice a voltage-drop of the order of 20 to 60 volts, but never much more; and therefore such a high voltage-drop as the theory demanded is very unsatisfactory.

With regard to the interpretation of the results, I would point out that, whilst the results as given are extremely interesting and instructive, a certain amount of caution is required in using them, because there is no principle of superposition for these effects. A knowledge of the deflectional and focusing characteristics for a group of frequencies does not enable one to deduce the response to a complex wave, because there is no superposition theory which allows this to be done.

In the paper by Prof. Parker Smith, Dr. Szeghö, and Mr. Bradshaw, the absence of origin distortion is referred to. The reason for this is fairly clear, because origin distortion is always a product effect, the two factors being the gas pressure and ray current. However high the gas pressure, we can make the effect small by keeping the ray current small. Another factor which masks the origin distortion is that in any case origin distortion is a fairly low threshold-voltage effect, and in this case a small threshold voltage will never be observed.

Mr. A. G. Warren: Referring to the paper by Prof. MacGregor-Morris and Mr. Henley, Mr. Hughes has already suggested that the unexpected sensitivity of the oscillograph to steady deflecting potentials does not call for the high negative potentials of the screen which the authors have suggested, but is accounted for by the field distribution between the potential deflecting plates. While it is probable that the authors have over-estimated the negative screen potential, I believe they are fundamentally right in attributing many of the operating features of the tube to it. Mention has been made of a measurement of potential of a metal-backed screen; the measured value was quite small. This is not evidence regarding the usual form of screen, over which great variations of potential are possible. I think that with steady deflecting potentials, or at low writing speeds, the negative potential at the writing spot may be quite high. This potential should be easy to measure. In the case of an X-ray bulb I have made similar measurements by connecting the point in question to the leaf of an electrometer, joining the case to a potentiometer, and adjusting the tapping for zero deflection. It seems to me that many of the idiosyncracies of the tube must be explained by variation of the potential between various parts of the screen. Taking Fig. 10A, for instance, it seems a severe criticism of the tube that one gets these differences between static potentials and rapidly varying potentials, and it is difficult to see how a gas-filled tube can ever become a precision instrument if this sort of thing may happen. The suggestion made by the authors on page 495, of definitely stabilizing the potential of the screen, seems to be a simple solution and would, I feel sure, contribute greatly to regularity in operation.

Turning to the paper by Prof. Parker Smith, Dr. Szeghö, and Mr. Bradshaw, it would be interesting to know how the current gets back from the screen to the anode. There are many possible ways, namely by leakage, by secondary emission, by positive-ion bombardment, and, in the case of this high-voltage tube, by conduction through the air. In the case of an X-ray tube a few per cent of the current actually passes through the air, and I should be interested to know the corresponding figure for the authors' tube. The inside of the bulb tends towards cathode potential and the outside towards earth potential; current passes through the glass, and can be measured by a sandwich of tinfoil and paper pasted on a spot on the glass, with a micro-ammeter connected between the two layers of tinfoil. There are plenty of X-rays, consequently the outside air is thoroughly ionized and is conducting; and one may find that a considerable fraction of the current is passing through the air. I should like to ask the authors what is the actual beam current as a fraction of the total current. For instance, in Fig. 4 they refer to the variation of intensity according to the current in the initial concentration coil. I should be interested to know whether the intensity increases as the current decreases, or whether they increase or decrease together. It might be imagined that when one is pushing more current on to the screen by concentrating the beam the intensity is increased and the total current reduced.

The gas pressure in the tube is extraordinarily high, and, as concentration coils are being used, I should like to know why it is necessary to introduce gas at all.

Why not use a hot cathode? The tube would be easier to adjust and the archaic osmotic regulator would be unnecessary. Of course, in gas-filled tubes one has to consider the filament, but it is a lucky evacuated tube that dies through its filament giving out; usually some other catastrophe occurs before that.

Mr. G. Parr: I should like to refer to the introduction of what I may call a "hybrid" tube, namely the high-vacuum sealed-off tube employing fairly moderate voltages. We know that an electron focusing device was developed a considerable time ago in the United States and has been employed in small portable tubes completely free of gas and the attendant disadvantages of gas focusing. There is no longer any need to worry about origin distortion or, within very wide limits, de-focusing of the spot at high frequencies. Those who visited the Physical Society's Exhibition which has just concluded will have seen there two examples, one in the research section and one in the trade section, of these high-vacuum tubes. The voltage employed is a little higher than in the case of the gas-focused tube, the sensitivity, however, being approximately the same. Origin distortion is completely absent, and the beam trace at frequencies of approximately 1–2 megacycles per sec. is still perfectly in focus. This tube might, I think, be borne in mind when the question of oscillograph equipments is being considered by research organizations. The ordinary research laboratory is probably unwilling to lay out £250 on oscillograph equipment, but possibly it would be content for the time being to compromise and have a tube giving rather better results than the gas tube but which does not require the often elaborate equipment of the high-voltage type. The cost of the equipment for the ordinary high-voltage small tube would seldom exceed about £50, and the technique and handling are very much the same as for the gas-focused tube.

Mr. G. A. Whipple: With regard to the paper by Prof. Parker Smith, Dr. Szeghö, and Mr. Bradshaw, I should like to emphasize the question put by Mr. Nuttall as to whether the life of the tube is limited by the eventual wearing-out of the spherical cathode or whether it is due to the fatiguing or burning of the fluorescent screen. If the latter, I consider the type of tube mentioned in the footnote on page 661 is very much to be preferred, chiefly because the small screen inside the tube can be made of metal. The high thermal conductivity of the metal screen enables it to stand up to intense bombardment. A zinc-sulphide-coated aluminium screen will stand up to a stationary 70-kV spot, whereas a glass screen is burned almost instantaneously.

I should very much like to ask at what voltage discharge occurs between the deflecting-plate systems in the oscillograph, as this seems to me to be a very great disadvantage of residual gas being left in this type of tube. Most workers on high-voltage high-speed oscillographs distrust potential dividers, but since inevitably these must be used the smaller or closer the ratio of division the better. If there is, however, quite a low limit to the voltage which may be applied between the deflecting plates of this type of oscillograph, I think it becomes a rather serious drawback. Further to this point, most workers are in agreement that the sphere-gap type of electrostatic single-sweep time-base operates most steadily at comparatively high voltages. If the voltage applied between the spheres must be kept low, the gap settings have to be small and critical, and the spheres well polished, if one is to obtain regular repetition of results.

Higher operating voltages render the performance of gap circuits more uniform and steadier. The discharge between plates mentioned by the authors as occurring at 2 000 volts would seriously limit the voltage permissible in the time-base circuit.

Dr. E. H. Rayner: The paper by Prof. MacGregor-Morris and Mr. Henley will be of great value in demonstrating to users of cathode-ray oscillographs the difficulties they will come across, and the nature and amount of the errors that they may have to anticipate.

The cathode-ray oscillograph, born 30 years ago, has now come into its own. I saw something of its birth in my days at Cambridge under Sir J. J. Thomson, who was present not only at the birth of the cathode-ray oscillograph but also, as I have heard him say, at the birth of the electron. Prof. Parker Smith's instrument, which has been demonstrated this evening, reminds me of the instrument I saw in Prof. Rogowski's laboratory when he brought out his large demonstration oscillograph, which was, I believe, about 10 ft. long.

It appears that the higher the writing speed in a vacuum-type cathode-ray oscillograph, the finer the trace. I am not sure that this is not a spurious effect, due to the use of a composite beam. In the normal case, when the writing is relatively slow, the outer parts of the beam may have some effect on the photographic plate, whereas at comparatively rapid writing speeds one may in fact be using only a small core at the centre of the beam, which gives rise to the effect I have mentioned. My colleagues have obtained traces of the order of 0·3 mm (0·018 in.) thick at a writing speed of 100 km per sec. At such speeds one can employ a comparatively small total size of oscillogram, because it can be measured with precision. If a large scale is required, troubles due to non-linear relation between deflection and voltage may arise.

The processes of continuous pumping and of changing the film are not really a difficult problem. The original metal oscillograph of Dufour required 40 to 80 minutes to pump out, whereas we can now exhaust a metal type of instrument in about 10 to 20 minutes. The speed of replacement of a film is greatly helped by a 4-stage mercury diffusion pump, which will operate with a backing pressure as high as 10 mm of mercury.

Equally good performance can, I understand, be obtained with an oil diffusion pump. We have had very satisfactory results with this type for other purposes, but have not actually used it for oscillograph work.

Mr. T. W. Price (*communicated*): Dealing with the paper by Prof. MacGregor-Morris and Mr. Henley, when the first gas-filled tubes were made this apparent discrepancy between the actual sensitivity and the theoretical sensitivity had been noticed, and when sensitivity curves were first drawn of the gas-filled tube we wondered why they should be curves instead of straight lines, and thought some error had been made in our

measurements. We are inclined to think that consistent tubes are difficult to obtain on a production basis with gas focusing, and that a uniformity of performance comparable with that of the mass-produced thermionic valve will only be realized when the cathode-ray tube is of the high-vacuum type with a vacuum of the same order as, if not better than, that of the ordinary radio receiving valve.

Do the authors consider that the wandering of the spot that occurs with gas-focused tubes on change of beam current is due to the change of potential of the screen with reference to the anode, or can this effect be put down to a slight shifting of space charge around the cathode when the cylinder bias is altered? This wandering of the spot with beam-current change is not apparent on high-vacuum tubes but only appears when softening occurs, and is a very useful indication as to whether the degree of exhaustion of the tube is satisfactory.

In the case of the high-vacuum tube it is very necessary to use a screen material having good secondary emitting properties, otherwise it is difficult to obtain a sharp spot focus, free from haze. Special materials are usually mixed with the fluorescent material to increase its secondary emission. This point is mentioned because it verifies, in a very practical manner, the generally-accepted theory of to-day that the beam current returns to the final anode in the form of secondary emission from the fluorescent screen, and not by interchange of electrons in the ionized gas.

With high-vacuum tubes, the return beam current is entirely dependent upon secondaries from the fluorescent screen, and this fact may to some extent explain why the focusing of the spot is not so good with low accelerator voltages.

The authors' suggestion that gas-focused oscillographs should have a conductive lining inside the glass envelope and on the surface of the fluorescent screen to dissipate bulb charge was tried some while back, but unfortunately the tubes proved quite unsatisfactory because the gas cleaned-up—in some cases within a few hours. This clean-up was considerably quickened with high accelerator voltages.

In the case of the high-vacuum tube it is advisable to use an internal conducting coating as an electrostatic shield to prevent defocusing due to the presence of bulb charges. I think it is better practice in the case of the gas-filled tube to have an external coating, especially around the deflector plates, as this tends to neutralize "wriggle effect" on the screen caused by oscillation of the beam in its travel to the screen.

The authors' conclusion that argon is the best focusing gas to use is in line with our experience. Argon is also cheaper and easier to purify than helium.

I should like to mention some of the advantages the high-vacuum cathode-ray tube enjoys over its rival, the gas-filled tube. Firstly, much improved life is obtained; secondly, the high-vacuum tube gives rise to no origin distortion; thirdly, no appreciable de-focusing occurs when using high radio-frequency potentials on the deflector plates; and fourthly, accurate so-called "modulation" of beam current can be obtained. This last application, of course, will be an essential when the cathode-ray tube comes into its own as *the* method of bringing good-quality television images into the home.

The Authors' Replies to the Discussion before the Meter and Instrument Section.

Prof. J. T. MacGregor-Morris and **Mr. J. A. Henley** (*in reply*): In the first place, an error in the paper should be noted; this occurs in col. 1, line 12, of page 494, where the pressure in the argon tube should be 8×10^{-4} mm mercury, as in Table 1.

We are grateful to Mr. Hughes for his valuable contribution to the discussion as a result of his recent work, indicating the direction in which the work described in the paper is being continued at Queen Mary College. In estimating the effects of screen potential we assumed that the charge was symmetrically distributed with respect to the axis, but it now appears that the fluorescent material is not a sufficiently good conductor for the charge to spread away from the neighbourhood of the fluorescent spot, where it can have only a small effect on the sensitivity. As Mr. Hughes points out, the anomalous sensitivity seems to be practically entirely due to lack of uniformity in the deflecting field, which we neglected when calculating the theoretical sensitivity.

It seems to be almost impossible to make accurate measurements of the screen potential in a normal tube because of the poor conductivity of the fluorescent material. Any attempts to modify this conductivity disturb the emitting properties of the screen, so that any results obtained are not applicable to normal glass-mounted screens.

Captain McGillewie contributes some valuable experimental evidence, but we are inclined to think that the change in sensitivity on connecting the conducting coating to the anode was due to modification of the fringing of the deflecting-plate field. This is because the tube used had no anode extension between the conducting coating and the deflecting plates.

As Captain McGillewie points out from his oscillograms, origin distortion is dependent upon beam current as well as upon gas pressure; this fact was mentioned in Section 4(*a*) of our paper. None of the oscillograms shown in Figs. B, C, and D (Plate 2, facing page 665), appears to be very well-focused, however.

The curves of Figs. 10A and 10B in our paper show practically no difference between the reductions in sensitivity with argon and with helium. This is because although argon is 10 times as heavy as helium, the pressure with the latter gas must be increased proportionately in order to maintain a sufficient ion density for focusing. The maximum frequency which can be applied to a tube without seriously decreasing the sensitivity is, however, greater with helium than with argon, as indicated in Section 4(*b*).

Loss of focus does, of course, depend upon transverse beam speed rather than frequency, although this speed is proportional to the frequency in our oscillograms, which are of approximately constant amplitude. The variation in speed from point to point over each trace

of Figs. 21 and 22 accounts for the differences in focus between the middle and ends. In order to obtain the optimum focus over the whole of a trace, uniformity of writing speed and therefore of ion density is essential.

Fig. F is a remarkably good example of high writing-speed with a gas-focused tube, although accurate camera tripping with a transient of this speed would be somewhat difficult.

As Mr. Bedford points out, our sensitivity curves are primarily of theoretical interest since they cannot be applied quantitatively to the complex waves which usually occur in practice.

We have already referred to the question of screen-potential measurement mentioned by Mr. Warren.

Messrs. Parr and Price refer to the high-vacuum oscillograph, which appears to be the successor to the gas-focused tubes because of the limitations of the latter instrument dealt with in our paper. The wandering of the spot with change of cylinder bias is familiar to most users of gas-focused tubes, and we consider that it is due to space-charge movement around the cathode; a contributory effect in some cases is caused by the earth's field, because of accelerating-voltage variation due to the regulation of the supply system with its series resistances. The variation of this effect with vacuum is interesting but difficult to explain unless the vacuum deteriorates sufficiently for a glow discharge to form between anode and cathode. Mr. Price's remarks on secondary emission are most interesting since in the high vacuum this is the only mechanism by which the electrons can reach the anode. We can only suppose that the gas clean-up with conductive tube lining was due to the use of graphite or some other material with a gettering action, since the metal anode extension has not this effect.

We deprecate the use of the term " gas-filled " instead of gas-focused for such oscillographs. The term "gas-filled " is reasonably appropriate when applied to tungsten lamps, as they operate at a pressure not far from atmospheric; but in the gas-focused oscillograph the pressure is only one two-thousandth part of one atmosphere, or even lower.

Prof. S. Parker Smith, Dr. C. E. Szeghö, and **Mr. E. Bradshaw** (*in reply*): We appreciate the interest in this paper that has been shown by speakers whose experience with various aspects of the cathode-ray oscillograph makes their contributions so valuable. In this connection, Dr. Miller's careful analysis is particularly welcome.

Several speakers have discussed the life to be expected from a sealed-glass-tube oscillograph. A life of about 1 000 hours is expected, but this is by no means a definite figure. Some tubes have failed earlier owing to cracks in the glass, whilst some have had longer lives, in spite of the fact that complete blackening of the discharge tube by cathode " dust " had occurred. A cathode movement of 1 mm is sufficient for about 10 hours' burning. On this basis it becomes clear that it is not the cathode life which limits the life of a tube; it would seem that the ultimate life of the tube depends on effects of the discharge, such as increased heating of the discharge tube.

Discharge between the trap plates occurred only with a certain magnetic field strength resulting from the use of a third concentration coil. This is a special case, and, though of interest as an example of the initiation of a gas discharge by a magnetic field, it does not affect the normal use of the oscillograph. Experiments have shown that such discharges do not occur between the deflection plates at voltages sufficient to produce full deflection with the least sensitive plates; thus the limitations suggested by Mr. Whipple are not apparent. The insulation resistance between the plates was determined with and without the cathode energized, and the same value was obtained in each case.

It was natural that much comparison with the continuously-evacuated type should be made. The advantages of the sealed type, such as simplicity, lightness, transportability, cheapness, constant readiness, external photography, suitability for demonstration, etc., warrant its development. Both types are relatively new, and capable of improvement. It would be a mistaken policy at this early stage to discard the development of an instrument so full of promise for college laboratories and capable of dealing with so many of the phenomena for which the more costly and elaborate metal tube is used. For this reason alone it is considered an advantage to have an example of the high-voltage sealed tube at the Royal Technical College, to enable experience with it to be gained in this country.

Dr. Miller asks as to the cost of the camera. This naturally depends on the aperture required, but, since it is needed for more or less monochromatic photography, elaborate and costly correction of the lens is unnecessary. The cost of the tube used in the demonstration was about £40. The amount of distortion is small when recording photographically the trace on the curved screen. The reason for the omission of the movable internal metal screens was difficulty of transport. As mentioned in the paper, it was found that the most suitable position for the bias coils was over the time deflection plates.

With regard to Mr. Wilson's suggestion that the loss of definition in Fig. 13(*c*), Plate 1, may be due to the presence of the gas in the tube, we do not think that this is the case. Experience has shown that at higher writing speeds the phenomenon mentioned by Dr. Rayner occurs and a fine trace is obtained; the loss of focus in this particular case is to be ascribed to maladjustment of the focusing coil. The suggestion that the earth's field compensation coils might be obviated by suitable screening has certain attractions, but the use of the coils was found generally more convenient. The possibility of repairing defective tubes has not been overlooked, and repairs are actually being carried out on the earlier tubes.

A tendency to oscillations in the trap-plate circuit, as suggested by Mr. Nuttall, has been confirmed, and the use of a damping resistance tried. Since the photographic plates are exposed only just before the record is taken, no trouble is experienced from any " retrograde rays " that may be present. In any case the fluorescent glow which these rays produce is very feeble.

In reply to Mr. Warren, we would say that the writing current of this sealed tube was not measured; but for

tubes of this type a ratio of writing current to anode current of 5 per cent may be taken as good (e.g. a writing current of 50 μA with an anode current of 1 mA).

We have always worked on the rising portion of the curve given in Fig. 4. Increasing the concentration current beyond the maximum results in a decrease of intensity, the anode current and writing current being practically proportional.

In spite of the fact that this tube has not the ability to write at the speeds attainable with internal photography the comparatively slow events in switching and transmission-line phenomena are well within the capabilities of the tube. For continuous operation in transmission-line work, the absence of water cooling has proved advantageous when the oscillograph is used in the field. Owing to the relatively slow phenomena encountered in this work a small anode current is used, and therefore but small heating of the discharge tube is obtained.

With regard to the possibility of simultaneously recording more than one quantity with the same oscillograph, reference may be made to several modifications of the sealed-glass type for this purpose.†

Comparing the earlier high-voltage, high-vacuum, hot-cathode tubes with the present cold-cathode tubes, the former suffered from insufficient control of the strong divergence of the ray. With increased knowledge of electron optics, it is hoped that it will be possible to improve this form of sealed tube so as to compete with the cold-cathode type.

Discussion before the Scottish Centre,* at Glasgow, 12th March, 1935, on the Paper by Prof. Parker Smith, Dr. Szeghö, and Mr. Bradshaw (see page 656).

Mr. J. Eccles: The diagram showing the connections for the recording of a transient (Fig. 8A) seems to indicate that prior to the occurrence of the transient phenomena the cathode ray has already been established and deflected into the beam trap.

In the practical work of recording transients on commercial networks it would, I think, be inadmissible to have a permanent cathode emission. This would in time damage the cathode surface, and as it might be weeks or even months before a surge occurred it would not be practicable to keep on moving the cathode ball to ensure that a fresh emission surface would be present when the phenomenon took place.

If a circuit could be devised whereby the cathode potential was applied by means of the surge itself, it would greatly increase the utility of the instrument for this class of work. The total time-lag between the inception of the surge and the commencement of the record would require to be not more than 1, or perhaps 2, microseconds. I should be grateful for any information which the authors can give regarding the possibility of arranging such a circuit, and the apparatus required.

Mr. C. H. Wright: The action of the solenoids surrounding the cathode-ray tube in focusing the spot is not clear to me, and I should be glad if the authors would give the physical basis on which they operate.

The cathode-ray tube has so many interesting properties that its applications are certain to grow in many directions. One suggested application already tried experimentally ashore is to use it as a compass or course indicator, to control the steering of a ship. If the cathode-ray tube is placed vertically the otherwise vertical ray (with a suitable controlling voltage) will be deflected by the earth's magnetic field, and accordingly the spot on the fluorescent screen at the end of the tube will describe a circle as the ship turns through 360°. In a tube tried for this purpose two electrodes at the end of the tube are so set that if the casing carrying the tube is turned in azimuth to the desired course, and there is any deviation from that course, the cathode-ray is brought on to one or other of the electrodes, the effect being amplified to operate a central-zero milliammeter. The pointer of this instrument remains on zero if the course is held, but if the vessel goes off the course set, the pointer is at once deflected to right or left. An obvious extension is to operate relays in addition to the central-zero indicator, and thus control the steering automatically and hold the vessel on its course. This instrument was developed by the Department of Scientific and Industrial Research, and was patented by Messrs. Watson Watt, Bainbridge-Bell, and Chaffer. Some tests have been made in Glasgow recently with the cathode-ray tube in this connection, but more development work remains to be done.

Mr. I. S. Scott-Maxwell: It seems that the low-voltage oscillograph possesses much the greater field of application. It is used in telephony research, radio engineering, by power engineers and manufacturers, and lastly, but not least, for television.

I have had some experience with a low-voltage tube, of slightly different construction from the low-voltage tube exhibited here, and which has maximum and minimum working voltages of 3 000 and 700 volts respectively. The frequency response of the tube I mention has a maximum of about 1 megacycle per sec.; and the only limit to transient investigation is the low value of actinic brilliance obtained on the screen with such a low anode voltage. This makes external photography rather difficult. On this small tube two waves can be produced together by employing some form of switching arrangement, either a commutator or valves. This enables one to obtain on the screen, alternatively, a voltage and a current wave following one after the other; 25 of each of the waves are produced per second, and owing to the time-lags of the screen and of the eye (due to persistence of vision) both waves are apparently seen at once. Such an arrangement behaves fairly well, but it has its limitations.

Turning to the paper, there are one or two points in regard to which I should like further information. Firstly, with regard to the cathode, in the paper it is stated that the sphere is made of aluminium. Is this aluminium coated with some other material? Secondly, in Fig. 1 the deflection plates c, c are of a special shape and not parallel to the centre line of the tube. I should like to know the reason for this.

* Joint meeting with the Scottish Students' Section.

† K. Szeghö: *Journal of the Royal Technical College*, 1935, vol. 3, p. 475.

With the development of the high-voltage sealed-off oscillograph and the resultant high intensity of fluorescence there has come a great reduction in deflectional sensitivity. Some sensitivity figures are given on page 661, and it is of interest to compare these with similar figures for the low-voltage tube. At 3 000 volts we have a sensitivity of approximately 15·75 mm per 100 volts for the low-voltage tube compared with 2·3 mm per 100 volts for a high-voltage tube; and at 700 volts, 59 mm per 100 volts compared with 7·5 mm per 100 volts. This means that large deflecting voltages are necessary in order to operate the high-voltage tube; so that, as the authors state, the high-voltage tube is practically limited to the investigation of transient phenomena, and other phenomena where high deflecting-plate voltages are possible.

Prof. M. G. Say: A demonstration such as that which has been given by the authors shows incidentally the immense and still growing importance of thermionics, or "electron engineering" as it might well be called. The thermionic vacuum tube, the cathode-ray oscillograph, and now also the thermionic gas tube, have grown in the last two decades to an importance such as to change the face of the electrical industry.

From the instrument described in the paper and demonstrated at this meeting, a few points of interest emerge, over and above the very considerable interest, not to say excitement, of seeing actual transient occurrences of duration a few microseconds made manifest on the fluorescent screen.

Firstly, the focusing seems to be very simple in this tube compared with the low-voltage gas-filled tube. There does not seem to be any means of focusing other than the concentrating coils. Is this because the gas pressure is lower than in the normal low-voltage unit? The so-called "gas-focusing" has received an adequate explanation: it would be of interest to have one for the behaviour of the concentrating coils. It would appear that some motion of the electrons other than that parallel to the ray must be presumed.

Secondly, the ray that reaches the screen is part of the current supplied to the cathode; this current presumably returns to the anode-cathode supply through the capacitance and leakance of the tube. Is this so, and does it suggest a reason for unsteady discharge, on the lines that a tube of small leakance might have an accumulating negative charge on its screen that might affect the operation? Finally, is it likely that the self-capacitance of the electromagnetic deflection coil would affect the record at the highest recording frequencies of which this tube is capable? I should like the authors' views on the upper voltage limits of the sealed-glass oscillograph.

Prof. S. Parker Smith, Dr. C. E. Szeghö, and **Mr. E. Bradshaw** (*in reply*): With regard to the recording of random transients, we presume that Mr. Eccles refers to circuits similar to those shown in Fig. 10. He is correct in suggesting that here the beam must be already burning. For the conditions he suggests, both continuously operating beams and automatic initiation have been used. The cathode voltage and the permissible delay in beginning the record will influence the design of circuits for automatic initiation of the beam. Methods similar to those in use for controlling time and trap circuits could be adapted to apply a voltage to the cathode, but difficulty in starting the beam might necessitate the use of other methods. One such method, giving a delay of less than 1 microsecond, employs a special discharge tube with a transverse beam continuously burning. The arrival of the transient causes a deflection of this beam which is made to bridge a spark-gap and so apply voltage to the main cathode.

Mr. Wright's interesting reference to the cathode-ray compass shows the versatility of the instrument.

In reply to Mr. Scott-Maxwell, we may say that the aluminium cathode is not coated in any way. The shape of the deflection plates to which he refers is to allow for the angular displacement of the beam during deflection. The limitations imposed by the low deflectional sensitivity do not in any way affect the use of the tube for the recording of cyclic phenomena, provided sufficient voltage is available to produce a reasonable deflection (see Figs. 11 and 12).

Prof. Say's suggestions concerning the mechanism of the return of the writing current to the anode are interesting. In this connection reference may be made to the contributions of Messrs. Warren and Price* in the discussion at London. With regard to the accumulation of a negative charge on the screen, it may be mentioned that in a similar instrument, but with a high-vacuum deflection chamber, a potential of 10 000 volts has been measured. We would point out that normally the use of electromagnetic deflection coils at high recording speeds is confined to the time-base circuit, and in the case of the time-base shown in Fig. 8A we have not experienced any difficulties such as Prof. Say suggests. With the present designs, the upper voltage limit for the sealed-glass oscillograph appears to be in the region of 60 kV.

Mr. Wright and Prof. Say ask for details of the lens action of the focusing coils. In this connection we may refer them to papers by Busch† and Brüche.‡ As Prof. Say suggests, the electrons have a velocity other than parallel to the axis of the tube, owing to their initial divergence.

* See pages 671 and 672 respectively.
† *Archiv für Elektrotechnik*, 1927, vol. 18, p. 583. ‡ *Ibid.*, 1935, vol. 29, p. 79.

VARIATION IN DISTRIBUTION OF WIND PRESSURE ON OVERHEAD LINES.*

[REPORT (REF. F/T93) OF THE BRITISH ELECTRICAL AND ALLIED INDUSTRIES RESEARCH ASSOCIATION.]

(*Paper received* 20*th March*, 1935.)

SUMMARY.

This report describes tests undertaken to ascertain to what extent lack of uniformity in the distribution of wind velocity along the front of a gust affects the total load on the towers of an overhead line. It is shown that on spans of length up to 300 ft. over level country, uniformity of distribution occurs. On larger span lengths uniformity is not maintained, measurements on a 600-ft. span showing a reduction of about 15 per cent per unit length of conductor as compared with the load on a 300-ft. span.

Over level country the height of tower will increase with span length, since conductors are erected with a constant minimum ground clearance. In general, the wind speed increases with height above ground. If then the simultaneous wind-loads on a number of spans of different lengths are compared, there will be a tendency for the load on a long span to be greater than that on a short span, and it is inferred that this tendency to increase the load will very largely offset the reduction in load due to limitation in the extent of the wind gust.

In the case of a long span over a valley, the measured wind load was found to be approximately equal to that calculated on the assumption of a uniform distribution of wind velocity as measured at the tower at conductor height.

CONTENTS.

(1) INTRODUCTION.

The wind pressure on the conductors of an overhead line forms by far the greater part of the transverse load which the supports are required to withstand. In calculations it is assumed that the load on a tower due to wind pressure on the conductors is directly proportional to span length. The tests described in this report were undertaken to ascertain whether this is the case, or whether lack of uniformity in distribution of wind velocity causes an appreciable reduction in the wind load on the supports as the length of span increases.

In addition to the possible variation in the horizontal distribution of wind velocity, it is well known that there is an increase of velocity with height above ground, so that in a discussion in which both of these variables are involved it is desirable to refer all wind velocities to one height, or to take one span length as the basis and to compare the wind load on it with the loads on other spans. The height of the supports increases with span length, and while theoretically there may be a different tower height for a given span for each conductor, economic and constructional reasons will, in practice, tend to bring heights for a given span length within fairly close limits. Thus if a number of typical spans of different lengths were erected one behind the other, having approximately the same ground clearance, and subjected to the same wind gust, comparison of the simultaneous wind load on each would provide a solution of the problem so far as lines over level country are concerned. Long spans (over 1 500 ft.) are usually of individual design, and are almost invariably situated over valleys or rivers. This case was investigated separately.

It will be shown that on the basis of comparison described, there was a decrease of about 15 per cent in the load as measured on the 600-ft. span from that on the 300-ft. span, and it is inferred that this decrease is not likely to be exceeded on spans of greater length because of the increase of height above ground. On a long span of 2 400 ft., the measured load showed no very definite decrease over that calculated on the assumption of uniform distribution of velocity as measured at the tower.

This report is not primarily concerned with what the safe wind velocity for design should be. There are clearly two cases to be satisfied, viz. a high wind velocity on bare conductors and a medium velocity on ice- and snow-loaded conductors. It is recommended that where possible, as in the first case, statistical analyses should be examined, as an aid in determining a reasonably safe velocity on which to design. Very heavy deposits on conductors are not of frequent occurrence, but it is known that wind speeds between 50 and 60 m.p.h. have coincided with deposits up to $\frac{3}{4}$ in. radial thickness. The actual pressure exerted per ft. run by wind on a coated conductor is not known. It is possible that it differs appreciably from that on either a smooth or a stranded conductor, but the distribution of wind pressure is equally important in both cases.

The problem of the distribution of wind velocity is by no means new. In general, it may be investigated either

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

by the employment of a large number of anemometers distributed along the span giving simultaneous readings of wind speed, or by the measurement of the actual load on the conductor, combined with wind measurements at one or two points. The second method has been employed in the tests described in this report.

Sir Benjamin Baker conducted experiments prior to 1884 to obtain reliable data on the effect of wind pressure on large structures. Under the direction of Sir Thomas Stanton,* tests were carried out on six stations 70 ft. apart at the National Physical Laboratory in 1911 and 1912, and later the tests were continued on Tower Bridge. As a result of these tests, it was stated that "the lateral variation in the velocity of gusts which strike a structure of 250 ft. span is of a much smaller order than has hitherto been supposed, and they point to the occasional occurrence of laterally uniform gusts."

Between 1926 and 1931, experiments were carried out at the Royal Airship Works, Cardington, by the Airship Division of the Meteorological Office. Valuable information was obtained regarding the structure of the wind, which was shown to consist, under most conditions, of eddies composed of alternating masses of fast- and slow-moving air.

Messrs. Sherlock and Stout† in America have recorded the instantaneous wind velocities at a number of stations 60 ft. apart, and have shown that the wind velocity may be uniform over a front of nearly 300 ft. An experimental overhead line with conductors strung on 40-ft. poles 120 ft. apart was also erected, with the intention of determining the total transverse wind load to which the poles were subjected by measuring their deflection. The results have not, however, been published.

Although the design of the measuring devices differed in different series of tests, the same fundamental method of measurement was adhered to in all the E.R.A. tests, both over level country and over a valley.

The principle used was that of measuring the angle of swing of the conductor under wind force. The weight of the conductor hanging from the point of support is known, and the horizontal force, i.e. the wind pressure, required to maintain the conductor at the measured angle of swing, is then obtained directly from the triangle of forces. Provided that the wind gust is of sufficiently long duration for the conductor to come to a position of rest, the method is accurate, and provided the points of support of the span are level the results are independent of temperature-change. The method is thus superior to a measurement of the change in tension of a conductor, which would necessitate the synchronization of temperature records as well as records of tension and wind velocity and direction. This consideration was important as it was desired to obtain continuous records throughout a winter, without constant supervision.

In both series of tests the conductor on which the measurements were made was the same size, namely steel-cored aluminium having 30 aluminium and 7 steel strands, each of diameter 0·102 in. The overall diameter was thus 0·714 in. and the weight 0·49 lb. per ft. Wind-tunnel tests were carried out on a sample length by the National Physical Laboratory, and the loads per

* See Bibliography, (1).

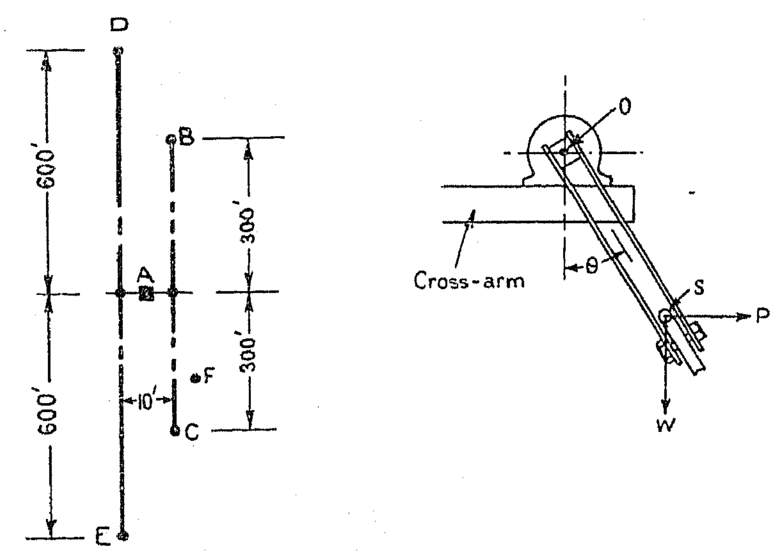
† *Ibid.*, (2) and (3).

ft. run are shown plotted against the square of the corresponding velocities in Fig. 3 and Fig. 5 (curve I).

(2) Tests Over Level Country.

Method of Test.

In this series of tests the simultaneous wind loads on spans of 300 ft. and 600 ft. were measured directly by apparatus actuated by the angle of swing of the conductors at the centre mast of an experimental overhead line consisting of two 600-ft. and two 300-ft. spans, erected on an open stretch of foreshore in Sussex, completely exposed to the prevailing winds. The arrangement is shown in Fig. 1(*a*), wherein A is a steel mast carrying two cross-arms from each of which the conductors are suspended by steel arms OS (Fig. 1*b*) capable of rotating about O in the vertical plane at right angles to the run of the line. Thus each arm supports half the weight of, and half the wind load on, each of the spans



(*a*) (*b*)

FIG. 1.—Arrangement of experimental line.
(*a*) Plan of overhead line.
(*b*) Details of swing arm.

on either side of it. By a suitable arrangement of rods and gearing, the angular movement of the swing-arms is transferred down the mast to the recording instruments situated in a hut on the ground. Three anemometers were erected—at A, B, and F. They were of the pressure-diaphragm type, and the charts ran at a speed of 3 in. per hour. To ensure synchronism between wind load and wind velocity, the chart drums in the hut were driven by the same shaft. The horizontal spacing of the conductors was 10 ft., the ground clearance rather more than 20 ft., and the conductors were erected with the points of support on one level. After erection, the apparatus was calibrated directly in pounds by applying a horizontal pull to the swing arms.

Results of the Tests.

The wind load as measured on the 300-ft. span was plotted against the maximum resolved component of the wind-gust velocity recorded at that instant on any one of the three anemometers, and the resulting diagram is shown in Fig. 3. The heavy curve shows the results of tests carried out in a wind tunnel by the National Physical Laboratory on a sample length of the conductor.

Coincidence of the measured loads and wind velocities with this line would indicate uniform distribution of wind velocity along the span, if the maximum velocity wind velocity occurs at times over a span length of 300 ft. The magnitude of the loads per ft. run on the 600-ft. span occurring simultaneously with these examples

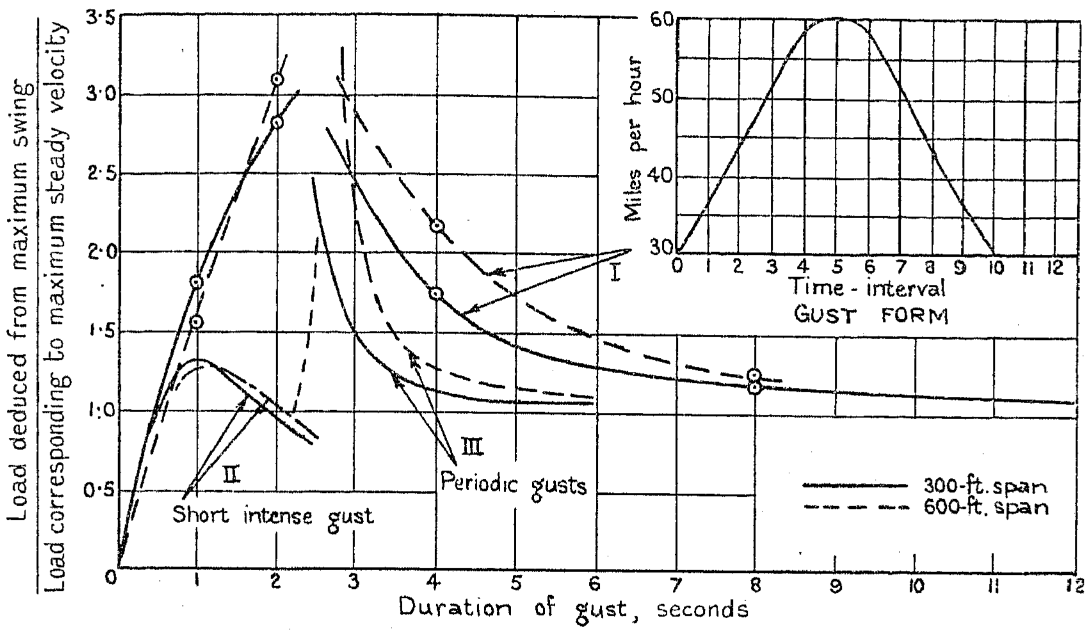


FIG. 2.—Effect of form and duration of gust on load measurements.

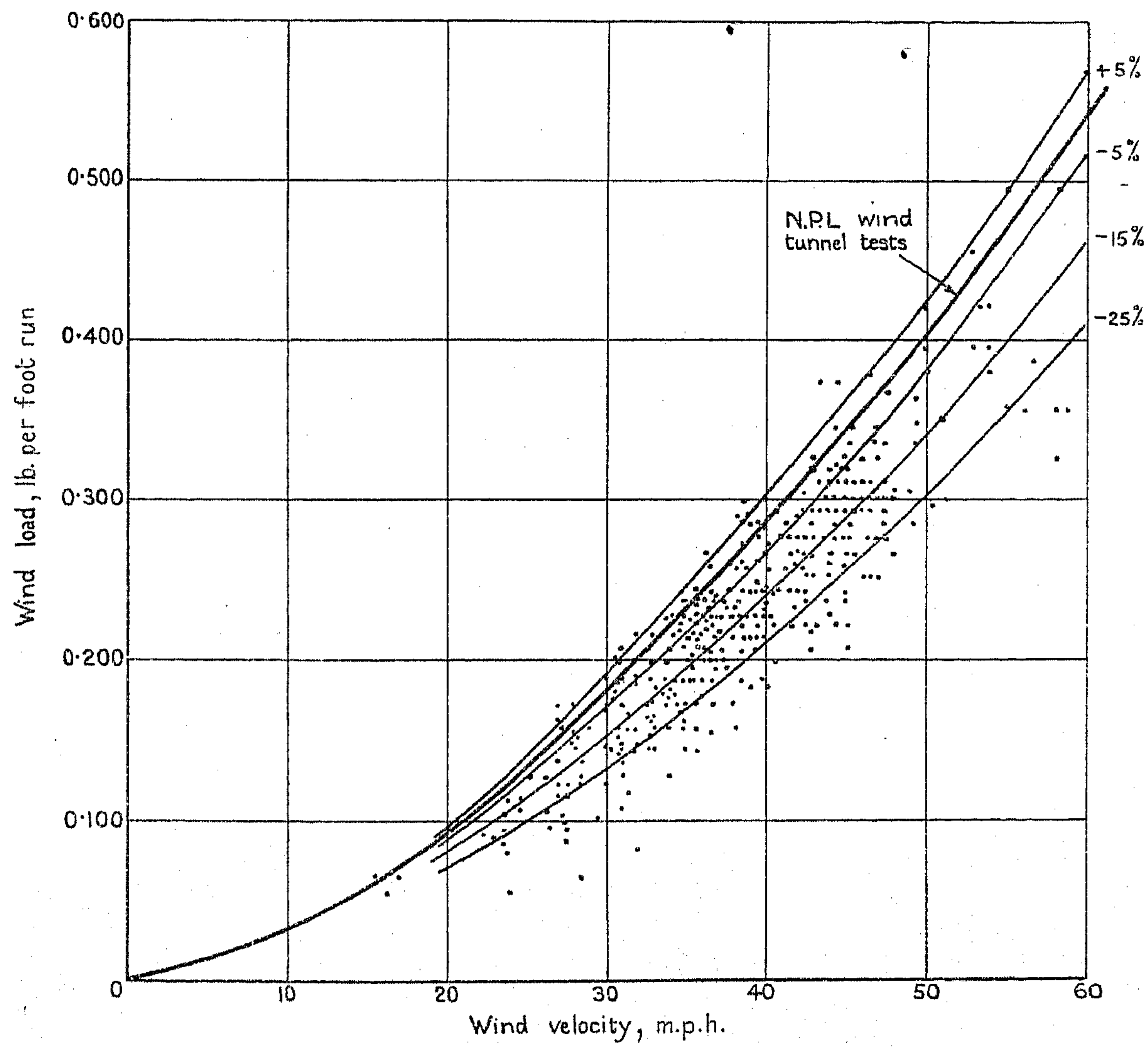


FIG. 3.—Wind load on 300-ft. span of 37/·102-in. steel-cored aluminium.

were actually known. The distances between the instruments were too great to ensure this with certainty, but there is little doubt that the correct order of magnitude of the wind speed was recorded. Hence from the number of points lying within ± 5 per cent of the heavy curve, it must be inferred that uniform distribution of of uniform distribution on the 300-ft. span never exceeded 0·86 of the load per ft. run on the 300-ft. span.

The maximum value of the resolved component of the wind velocity at right angles to the line was 58·5 m.p.h. As there was no difference in the values of the load ratio between the two spans at different wind velocities, there

is no evidence that at high wind velocities the lateral distribution of the wind gust would be appreciably altered.

On the whole, therefore, the conclusion may be drawn that *the distribution of wind velocity over the wind front is such that the effective pressure on a 600-ft. span over level country is about 15 per cent less than the value equivalent to uniform distribution.*

Fig. 4 (see Plate facing this page) illustrates a record of a squall, and shows the response of the recording instruments. The sharp change in wind direction coinciding with the squall should be noted; it brought the wind direction almost exactly normal to the line.

Effect of Gust Duration on Measurement of Wind Load.

Reference has been made to the fact that the method of measurement of the wind load assumes that the conductor is in a position of equilibrium when the observations are made. This matter was examined in some detail. The angle of swing of a conductor depends on the character of the gusts and the relation between their duration and the time-period of free oscillation of the wires.

Lamb* has given a solution for two specific cases: (*a*) The free motion of a conductor after the passage of a violent gust of short duration. (*b*) The motion due to wind gusts of regular periodicity. There is a third case of importance, namely, that in which the wind gust is of sufficient duration for the maximum swing of the conductor to be reached during the passage of the gust. This case is difficult to treat rigidly, but by assuming a regular form for the rise and fall of the wind velocity (see Fig. 2), and by employing successive integrations, an approximate solution can be found. The actual form of the curve showing rise and fall of velocity is unknown in any case, and is no doubt very irregular, but it is considered that calculations based on the three cases noted above gave useful information as to the behaviour of the spans.

Thus from the known values of mass, sag, and time-period of free oscillation of the two experimental spans, the maximum angle of swing of each was calculated for each duration of gust, and the corresponding load deduced.

It was shown that when the duration of the gust reached about 8 sec., the error introduced into the ratio of the load on the 600-ft. span to the load on the 300-ft. span, by the assumption of equilibrium, is reduced to about 2 per cent (Fig. 2). Although the actual form of the wind gusts could not be determined from the examination of the charts, the number of peaks in a given time was counted, and from these data it appeared that the duration of the major wind gusts was of the order of 30 sec. Moreover, Fig. 3 shows that comparatively few of the wind loads were greater than those deduced from the laboratory tests. Hence, in general, it can be inferred that the gusts were of sufficient duration for accurate readings to be obtained.

(3) Tests on a Long Span Over a Valley.

General.

This series of tests was carried out on a span length of nearly 2 400 ft. over a valley in the Yorkshire hills. The maximum sag of the conductors was about 130 ft., and the height of the lowest of them above the bottom of the valley in the centre of the span was 160 ft. The wind load was measured at the tower, and the wind velocity and direction were recorded there also. The latter may therefore differ somewhat from the air conditions over the centre of the span, both in velocity and in direction of flow. Observations were carried out during two winters. Unfortunately, the general direction of winds of high velocity was not normal to the span, so that the resolved components were not of high speed, the highest recorded being 41 m.p.h.

Briefly, the results of these tests showed that the mean wind load on the tower was greater than that to be expected from the corresponding mean wind velocity *as measured at the tower*, and secondly, that the maximum wind load during a gust sometimes appeared to be as great as that due to a uniformly distributed wind velocity equal to that of the gust as measured at the tower. A probable explanation of these observations is that the wind velocity in the centre of the span is greater than that at the ends.

As a means of confirming or disproving this assumption, the formula

$$v_h = v_{33}(0\cdot4 + 0\cdot4 \log h),$$

where v_{33} is the wind velocity in m.p.h. at 33 ft.
and v_h the velocity at h ft.,*

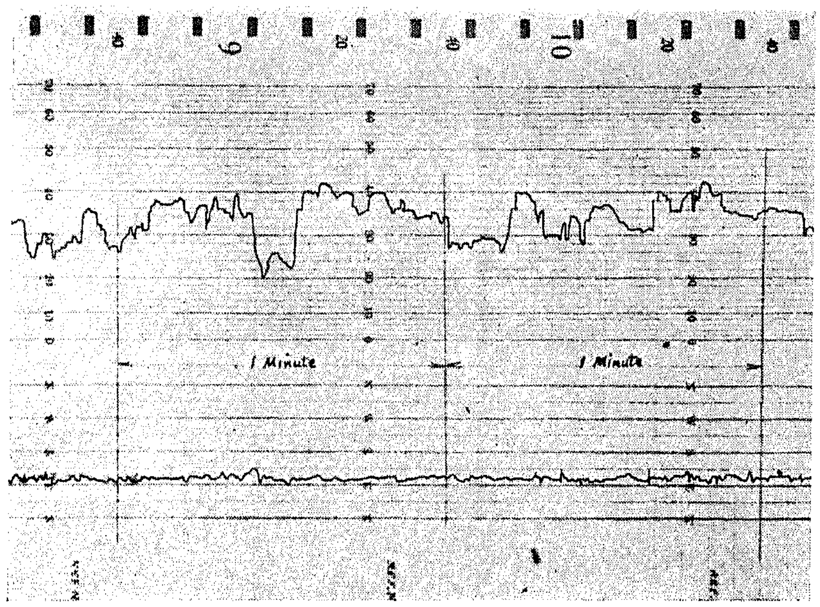
was applied to this span over the valley. Since the formula was derived from tests over level country, there is no absolute justification for applying it to the case of a valley. The load as calculated on this assumption is, however, sufficiently close to the measured load to indicate that the suggested explanation is not far from complete. The three curves in Fig. 5 show the relationship between the measured mean wind load on the tower; and the wind load calculated from the wind velocity as measured at the tower, and uniformly distributed along the span; and the wind load calculated from the wind velocity at the tower, corrected to account for the increase in height of the conductor above ground, using the above formula.

Fig. 6 shows wind loads corresponding to maximum gust velocities as measured at the tower. The upper limit curve (curve IV) round these observations is so close to that corresponding to uniform distribution of the wind velocity at the tower (Fig. 5, curve I) that, in practice, it is clear that the towers supporting a long span must be designed to withstand the full load corresponding to the maximum wind velocity, *and that no reduction is permissible in load per ft. run of conductor on account of limitation in the lateral extent of a wind gust.*

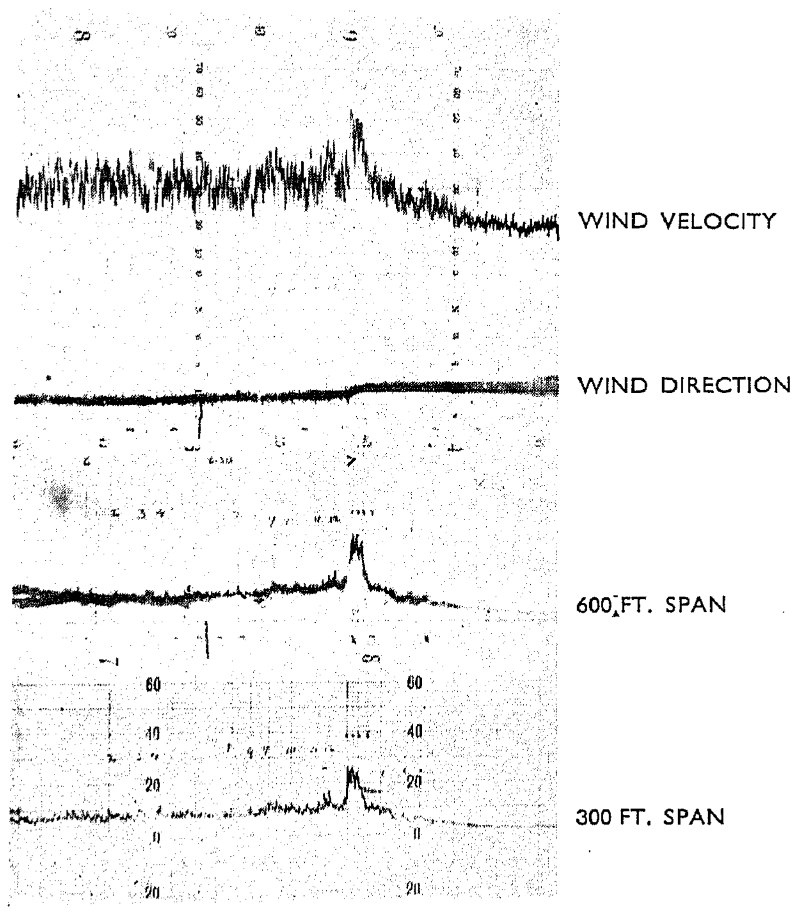
This does not necessarily imply that the wind gust was uniformly distributed along the span. Indeed, if the curve relating maximum wind load to maximum gust velocity (curve IV, Fig. 6) is compared with that relating mean wind load and mean wind velocity (curve II, Fig. 6), both wind velocities being measured at the tower, it will be observed that the loads due to gusts are about 20 per cent less than those due to mean wind velocities. This view is supported by the fact that while there is

* See Bibliography, (4).

* See Bibliography, (5).



(*a*) Quick run, showing wind velocity and direction.



(*b*) Sudden gust, showing response of instruments.

FIG. 4.—Instrument records.

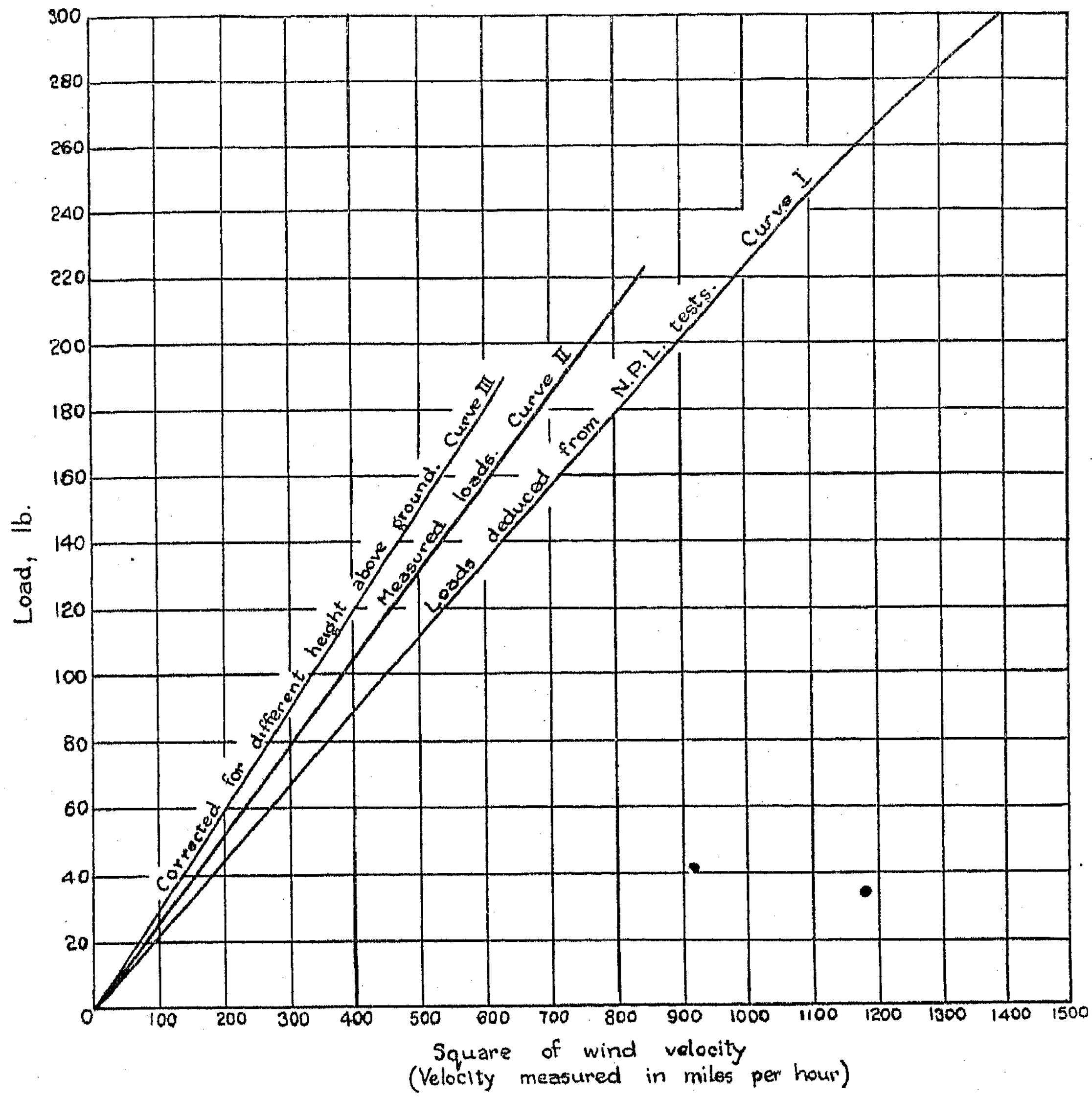


FIG. 5.—Wind load on tower due to wind load on conductors (2 400-ft. span).
Curve I shows relation between wind load (as deduced from wind-tunnel tests) and square of wind velocity.
Curve II shows relation between wind load (measured) and square of average wind velocity (measured at tower).
Curve III shows effect on Curve I of making allowance for increased height of conductor above ground according to assumed relation: $v_h = v_{33}\,(0\cdot4 + 0\cdot4 \log h)$.

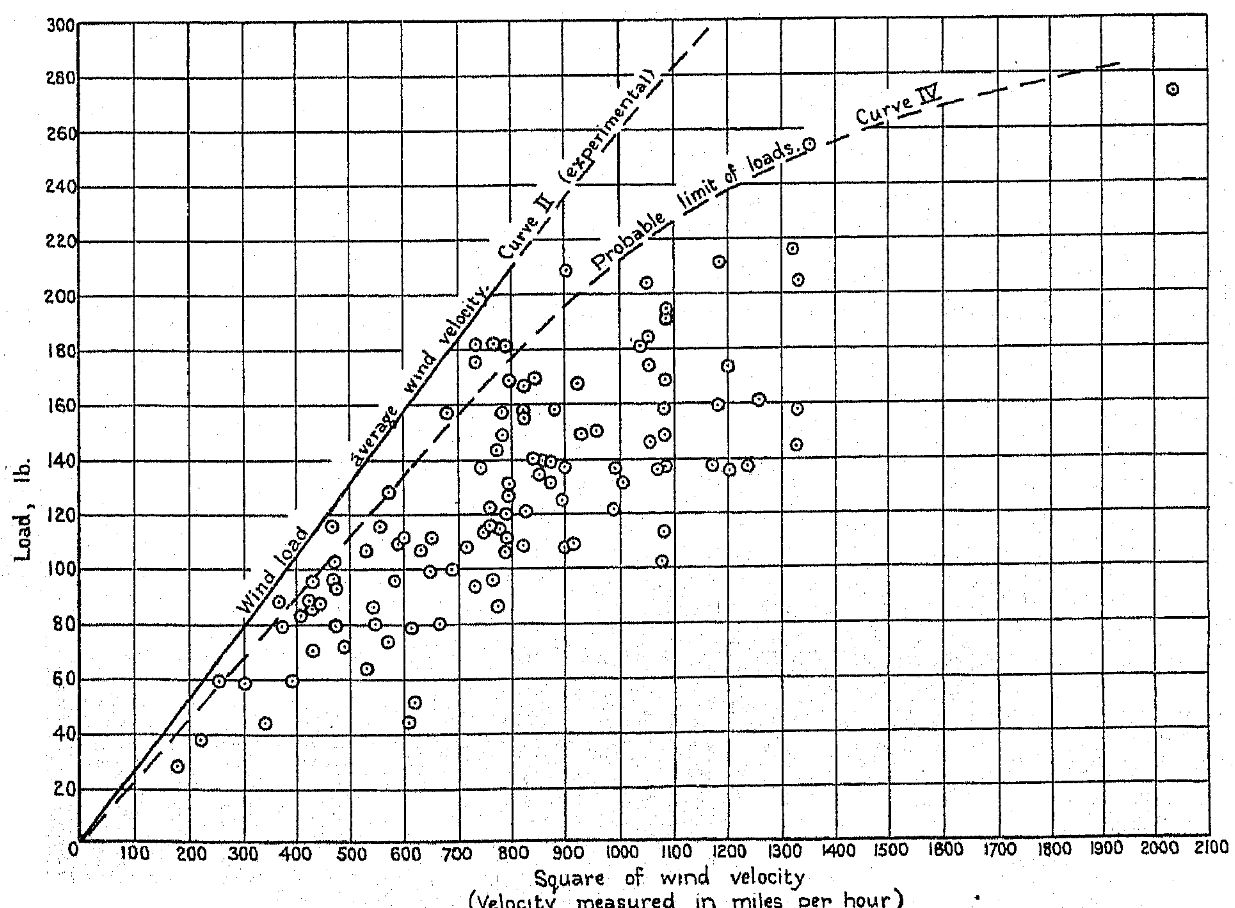


FIG. 6.—Wind loads due to wind gusts (2 400-ft. span). Values measured at one of the supporting towers.

general similarity of outline between the wind-load and the wind-velocity charts, there was by no means point-to-point correspondence. The inference may be drawn that, over the length of conductor supported by the tower (i.e. 1 200 ft.), the wind load due to the passage of a gust would have been about 20 per cent less than that due to a uniform wind speed equal to the maximum velocity of the gust, if the measurements had not been complicated by variations in wind velocity due to difference in height. This figure must, however, be taken with reserve.

Description of Test Gear.

A short description of the gear used in these measurements should be of interest, because, as the power line was alive throughout the tests, and as the earth wire on which the tests were carried out was insulated by three strings of tension insulators, each of six 10-in. discs, special means had to be adopted. The measuring

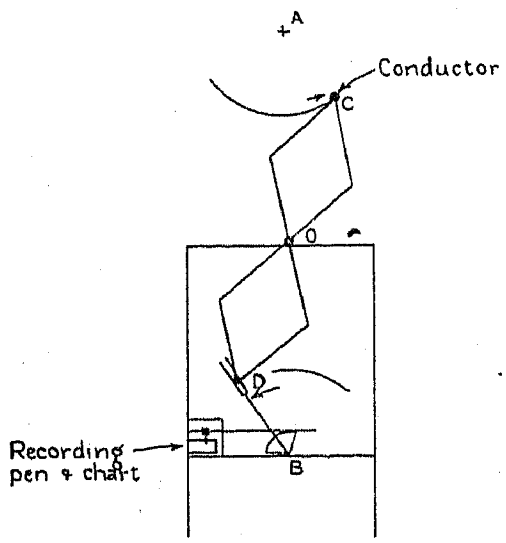


FIG. 7.—The "lazy-tong" mechanism.
AC represents sag of conductor.
$\angle DBO = \angle CAO$

gear had to be designed so that it would not interfere with the safe working of the line, and could be disconnected at short notice. This difficulty was overcome by erecting the measuring gear below the conductor and reproducing its swing by means of a "lazy-tong" mechanism as shown in Fig. 7. Here it will be observed that the swing of C (a point on the conductor) about A (on the chord connecting the points of support of the span) is reproduced by the swing of point D about B. A slot in the lever BD at D allows variation in the length of BD to correspond to variations in length of AC, i.e. in the sag of the conductor. A rack-and-pinion gear at the pivot B translates the rotation of the lever to a linear motion of a pen recording on a chart housed on the frame. The chart on which the wind velocity and direction are recorded is carried on a prolongation of the same drum to secure synchronization.

Two similar sets of measuring gear were installed at different distances from the tower, and accurately aligned beneath the conductor. By comparing the simultaneous readings of these two instruments the actual angle of swing of the conductor could be found, and the effects which would otherwise have been introduced by the presence of the heavy insulator assembly were avoided.

(4) Variation of Wind Velocity with Height above Ground.

On the ordinary overhead line, the heights of poles and towers range from 40 to 80 ft. From information supplied by the Meteorological Office regarding tests over open grass country at heights between 2 and 60 ft., the following formula (to which reference has already been made) has been derived to show the variation of wind velocity with height above ground:—

$$v_h = v_{33}(0\cdot 4 + 0\cdot 4 \log h)$$

Published results of tests made by French observers at St. Inglevert and la Couarde (at 2 to 12 metres), and by W. Schmidt* (1 to 10 metres), show a variation of the same order. In a report on "The Structure of the Wind over Level Country," published by the Meteorological Office,† it is shown that the ratio of the mean hourly wind speeds at 150 ft. to those at 50 ft. tends to a value of about 1·2. In the case of the maximum hourly gusts the value of the ratio is about 1·2. From the above formula the ratio of the wind speed at 150 ft. to that at 50 ft. is calculated as 1·18, and supports the view that the formula given can be used with fair accuracy. Owing to the turbulence of the winds, large differences may be expected in any particular case, but, taking a very large number of observations as a whole, it is considered that the above relationship expresses a representative case.

(5) General Discussion on the Effect of Length of Gust Front on Resultant Wind Load.

Summarizing the conclusions reached, it is found that the wind gust exerts full pressure on conductors of lengths up to 300 ft. On a span length of 600 ft. there is a diminution of pressure of about 15 per cent, and it has been shown in Section (3) that on a length of 1 200 ft. it is possible that the decrease amounts to 20 per cent [see Fig. 8(*a*)]. This latter figure, however, assumes that the whole 1 200 ft. is at the same height above ground, and, although giving a measure of the lateral extent of the wind gust, it could not be applied in practice, where the conductor would not be at a constant height above ground.

The effective pressure per foot run cannot decrease indefinitely as the span length increases. If it is assumed that the wind consists of a number of whorls all moving forward with high velocity, then in effect the wind front consists of a number of gusts each of limited extent, so that, as the span length increases, the effective pressure on the conductor becomes less dependent on the character of the individual gust, and assumes a value which is the sum of the pressures due to a large number of gusts and troughs. Some indication of the lowest effective pressure per foot run can be obtained by considering that the maximum gust velocity is generally between 1·4 and 1·5 times the mean wind velocity. Now the effective pressure on the conductors, as longer lengths of wind fronts are considered, will not fall below that equivalent to the mean velocity. As the pressure is approximately proportional to the square of the wind velocity, the load corresponding to the mean velocity will hardly be less

* See Bibliography, (6). † *Ibid.*, (7).

than about 0·5 of that corresponding to the maximum velocity of the wind if uniformly distributed.

Some corroboration of the results given above can be obtained from outside sources. Sir Thomas Stanton's experiments on Tower Bridge showed that gusts sometimes exerted their full pressure over a length of 225 ft. Approximate calculations of wind load from the published iso-velocity charts of Sherlock and Stout, show that there is little reduction in load up to a span length of 480 ft. as to the height of supports for given span lengths, and since the wind load has been shown to be substantially uniform over 300 ft. this length has been taken as basic and all wind loads referred to it.

Thus Fig. 8(*c*) shows the total effective wind load on spans of different lengths (over level country). Strictly, of course, it applies only to one selection of pole heights, but the general trend of the results will not be materially affected by a different (practical) selection.

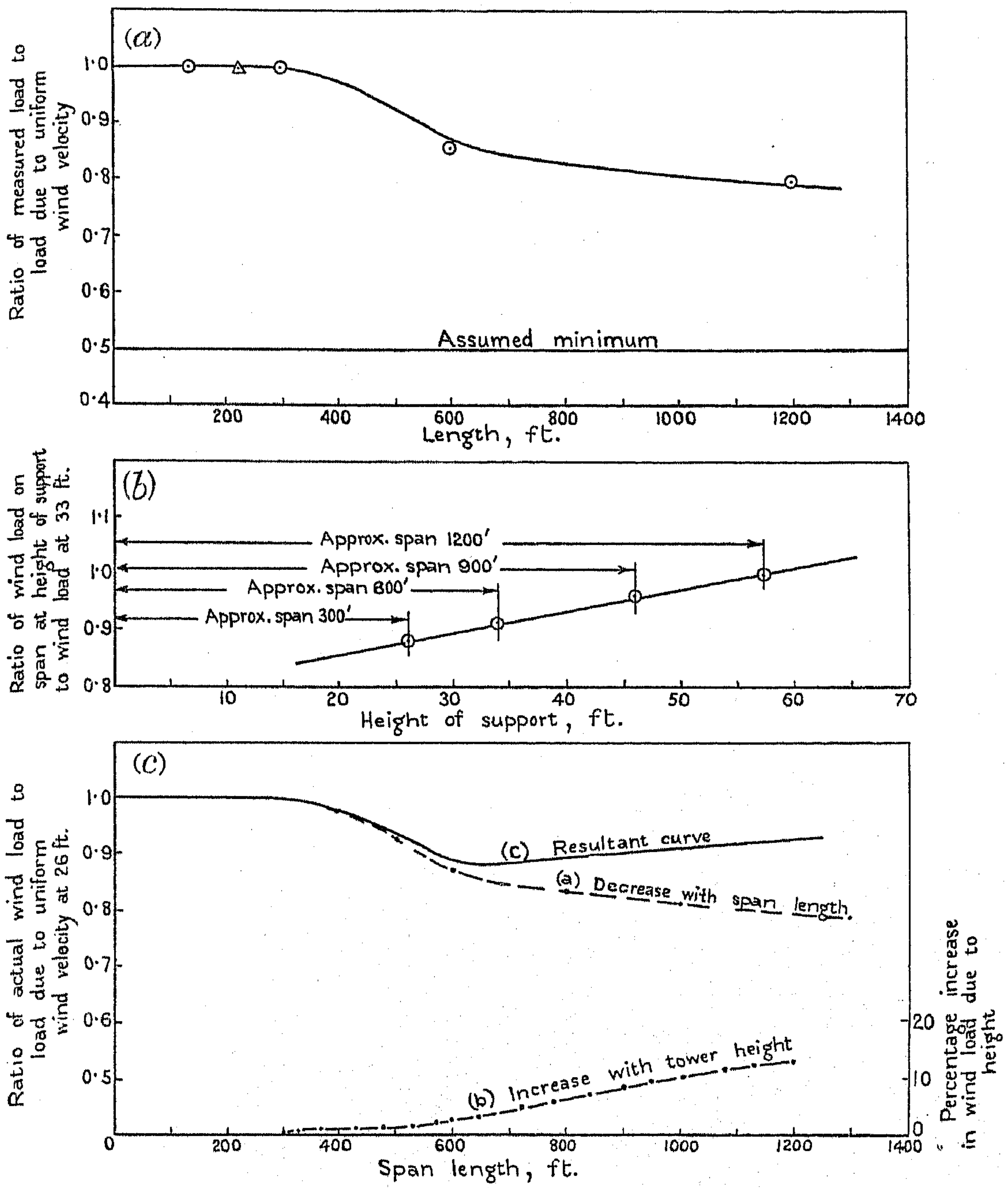


FIG. 8.—Variation of wind load with span length.

(*a*) Variation of wind load with length of gust front.
(*b*) Variation of wind load with height of support.
(*c*) Resultant variation of wind load with length of span.

NOTE.—In this figure it is assumed that the height of the lowest conductor on a 300-ft. span is 26 ft.

Since an overhead line is constructed with a minimum ground clearance (and over level country this occurs in the centre of the span), the total wind load will, in general, increase with the height of the support. Assuming the relation given in Section (4), and a minimum clearance of 20 ft., Fig. 8(*b*) shows the variation with the height of support in the load per ft. run on a catenary as compared with the load per ft. run on a conductor held uniformly level at a height of 33 ft. above ground.

It remains to combine Figs. 8(*a*) and (8*b*). This can only be done by making certain reasonable assumptions

It will be seen that the decrease in effective wind load as the length of the span increases, taking into account both horizontal and vertical variations in wind velocity, will not exceed about 15 per cent of that due to uniform distribution of wind velocity on a 300-ft. span, and in general will be less than this value.

(6) CONCLUSIONS.

The results of these tests show that over level country there is a slight decrease in the wind load on the conductors due to a limitation in the lateral extent of a wind gust.

The decrease is not appreciable on span lengths less than 300 ft. On a length of 600 ft. the decrease in wind load amounted to about 15 per cent. It has been shown that, compared with the load on a 300-ft. span, this decrease is not likely to be exceeded in the case of overhead lines of greater span length, because the height above ground of the towers and conductors is increased as the span length is increased.

In the case of a long span over a valley, no reduction in load per ft. run was definitely found. The load which the tower was called upon to sustain was of the order predicted from wind-tunnel tests on similar conductor, referred to wind velocities as measured at conductor level at the ends of the span.

(7) Acknowledgments.

The thanks of the Association are due to the Yorkshire Electric Power Co. and to the County Borough of Brighton, for valuable assistance and facilities given during the investigations described in this report.

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VOLTAGE VARIATION AT CONSUMERS' TERMINALS.*

By E. B. WEDMORE, Member, and W. S. FLIGHT, Associate Member.

[REPORT (REF. Z/T41) OF THE BRITISH ELECTRICAL AND ALLIED INDUSTRIES RESEARCH ASSOCIATION.]

(*Paper received* 14*th March*, 1935.)

SUMMARY.

The first part of this report deals with the distribution of voltage-variation characteristic of electricity supply systems in this country, a subject apparently not hitherto investigated, and contains novel suggestions as to the preparation and study of records of this character. The second part deals with the effect of variation upon the performance of different classes of electrical apparatus. The third part contains a general survey of the problem of control of voltage variation from a theoretical standpoint, but leading to conclusions of practical interest. This is followed by a summary of Conclusions.

The reader is warned against assuming that calculations and examples representing extreme or exceptional conditions are representative of general practice. A clear distinction is drawn in the text between normal and abnormal cases.

Further consideration is being given to methods of measurement, more especially instrumental methods.

Meanwhile the Director of the Electrical Research Association will welcome comments and suggestions from those who may have occasion to make use of this report.

CONTENTS.

* This paper is to be read and discussed at a meeting of the Transmission Section during the session 1935–1936.

CONTENTS—*continued.*

III. CONTENTS—*continued.*

(*e*) Time factor in measurement of maximum variation.

IV. Summary of Conclusions.

Appendix: Correlation of Voltage at a Consumer's Terminals with Feeder Load and the Consumer's Load.

I. EXPERIMENTAL INVESTIGATION OF VOLTAGE VARIATION.

(*a*) *Introduction.*

In the distribution of electrical energy it is not possible to maintain the same voltage at the terminals of all consumers, and certain variations from the declared voltage are permitted.

Under certain conditions it may not be economically possible to maintain the voltage at all times within the permitted limits. Further, on most systems the voltage at the terminals of the more distant consumers is liable to be low at periods of heavy load which usually represents the periods when the consumer wishes to use electricity, while during the night and light load periods the supply may be at its best.

The voltage variation is generally observed by the use of recording instruments, but hitherto no attempt has been made to study statistically the "distribution" of voltage variation, i.e. the relative frequency of different amounts of departure from normal. Such a distribution curve gives a picture of the quality of the supply.

A statistical study has been made by the Association, but owing to the expense of the recording instruments, only a small number were available, and consequently the period of observations on any system or any part of a system had to be limited. There is reason to believe, however, that the tests made were of sufficient duration to give a representative picture of the supply.

(*b*) *Systems on which Tests were Made.*

(i) An underground distribution with about 40 000 consumers, load approximately half domestic and half industrial. Automatic regulation at power station.

(ii) An underground distribution with about 8 000 consumers, load mainly domestic. Hand regulation.

(iii) An overhead distribution serving a scattered rural district with both a high-tension and a low-tension supply, the load being approximately half domestic and half industrial. Hand regulation.

(iv) A low-tension overhead distribution serving a residential district where electricity is extensively used. Hand regulation.

(v) A large interconnected high-pressure system supplying a number of general distribution substations in addition to a number of power supply substations for collieries, shipyards, works, etc.

(vi) Certain London supply systems (a few observations only).

(*c*) *Method of Test.*

For a period of at least two weeks a recording voltmeter was connected to the terminals of a consumer situated at a considerable distance from the supply. During the same period a similar voltmeter was connected to a consumer nearer to the supply. A recording ammeter was placed in the feeder at the source of low-tension supply. In some cases recording ammeters were placed in the consumer's circuit, and in some cases

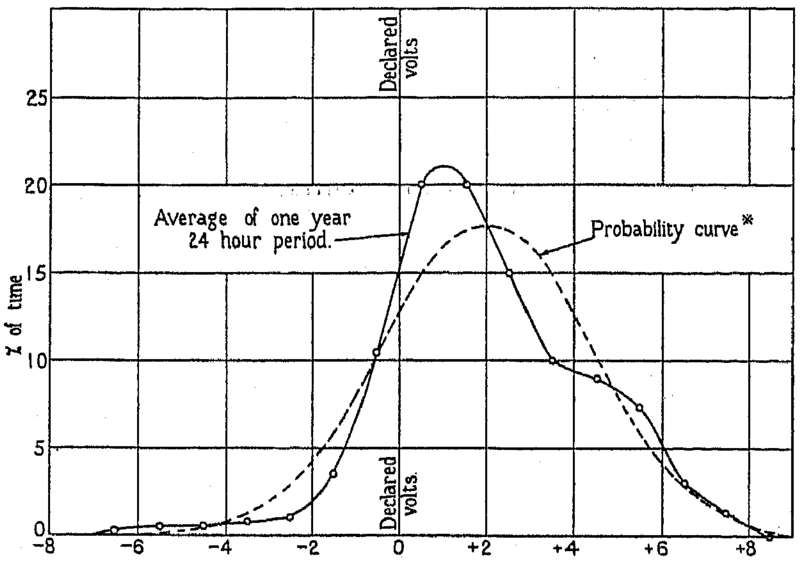

FIG. 1.—Voltage distribution with time for system (*b*) (ii). Average of various consumers at different parts of the system. High-tension supply by 2 250-V underground cable, average length to local substation = 1·3 miles. Average distance of consumer from substation = 270 yards. No local regulation. Hand regulation at power station.

* The probability curve is derived from the experimental curve, and shows the true underlying voltage distribution which would be obtained if a great number of voltage records were taken and the voltage steps were very small.

recording voltmeters were connected at various points of the distribution system.

Consecutive weekly records showed but little change in the characteristics of the supply and load.

To explore the yearly characteristics, records were taken at the same place at suitable intervals during the 12 months.

(*d*) *Instruments.*

Recording ammeters of the moving-iron type, fitted with continuous recording pen, were used, also recording voltmeters of the moving-iron type recording by means of a tapping bar depressing the pointer and printing a dot on the chart once every minute. The above instruments and the necessary current transformers were manufactured by Messrs. Evershed and Vignoles, Ltd., who state that the accuracy of the voltmeter indications are within plus or minus 0·25 per cent. The recording voltmeters were set by means of a sub-standard voltmeter.

(e) Analysis of Voltage Distribution with Time.

At the initiation of the research it was suggested to take voltage records showing the distribution with time. The method of analysis thus consisted in adding up the total number of minutes, during any selected time period, when the voltage was between any selected voltage range, the voltage steps being taken at 1 per cent volt intervals. Examples of the curves obtained are shown in Figs. 1, 2 and 3.

Each of these curves represents the result of an analysis of the 24-hour period. In Fig. 3 it will be seen that the two humps are caused through the superimposing of two different sets of conditions, i.e. the voltage during the night period tending to stabilize round a different value to the day period.

The double-hump characteristic is not shown by the corresponding curve in Fig. 2 for the summer period,

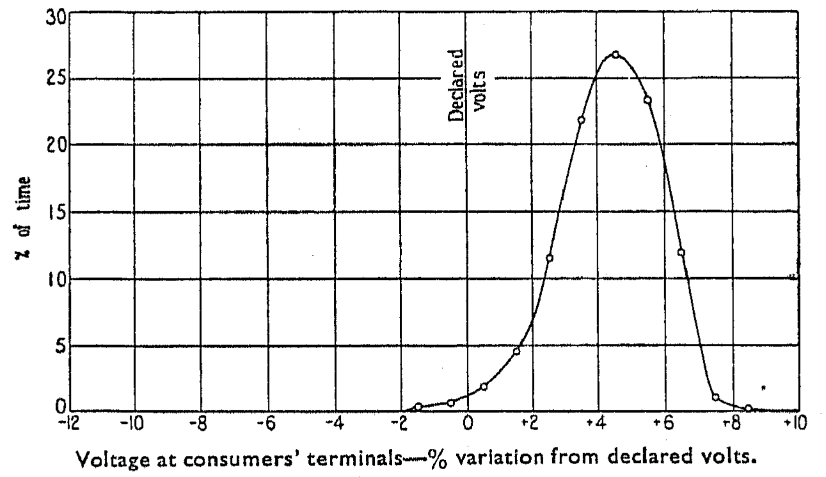

FIG. 2.—Voltage distribution with time. [System (*b*) (i)]. Average for summer months, 24-hour period.

possibly because, the lighting load being relatively small, regulation is easier and, incidentally, the average voltage is higher.

Another example of the double hump due to different conditions during the day and night periods is shown in Fig. 10; in this case the night load is considerably smaller than the day load, and for most of the night the voltage is very steady and the hump on the positive side of the curve is thus high.

Examples of 24-hour distribution curves with three humps are shown in Figs. 4, 5, and 6.

These curves represent exceptional conditions in outlying parts of local distribution systems forming part of a large system in which the regulation generally is good. They are attributable to the superposition of three sets of conditions. In each case the local supply is obtained from and controlled by a large distant system.

Where a considerable cooking and heating load was connected on a low-pressure distribution system it was found that, in addition to the winter evening peak load, a heavy morning peak load occurs during the breakfast period.

In residential districts the load is mainly confined to a period less than 24 hours, such as 7 a.m. to 11 p.m. This period is referred to in the report as the "use period" and varies with the district and the time of the year.

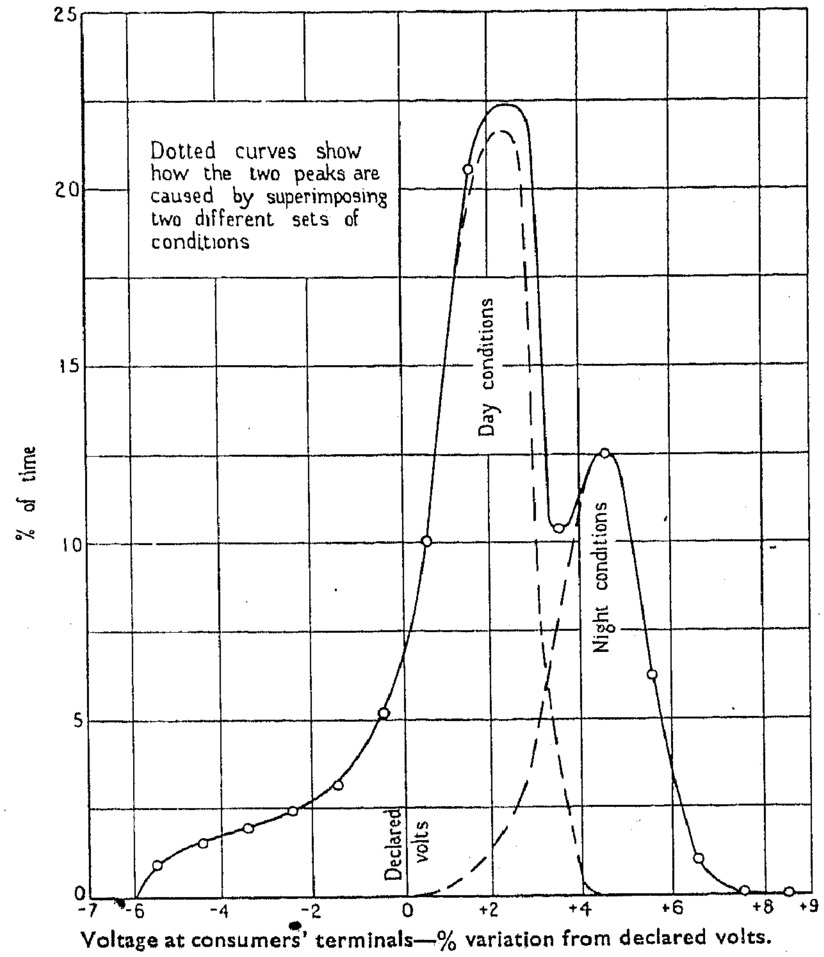

FIG. 3.—Voltage distribution with time. [System (*b*) (i)]. Average for winter months, 24-hour period.

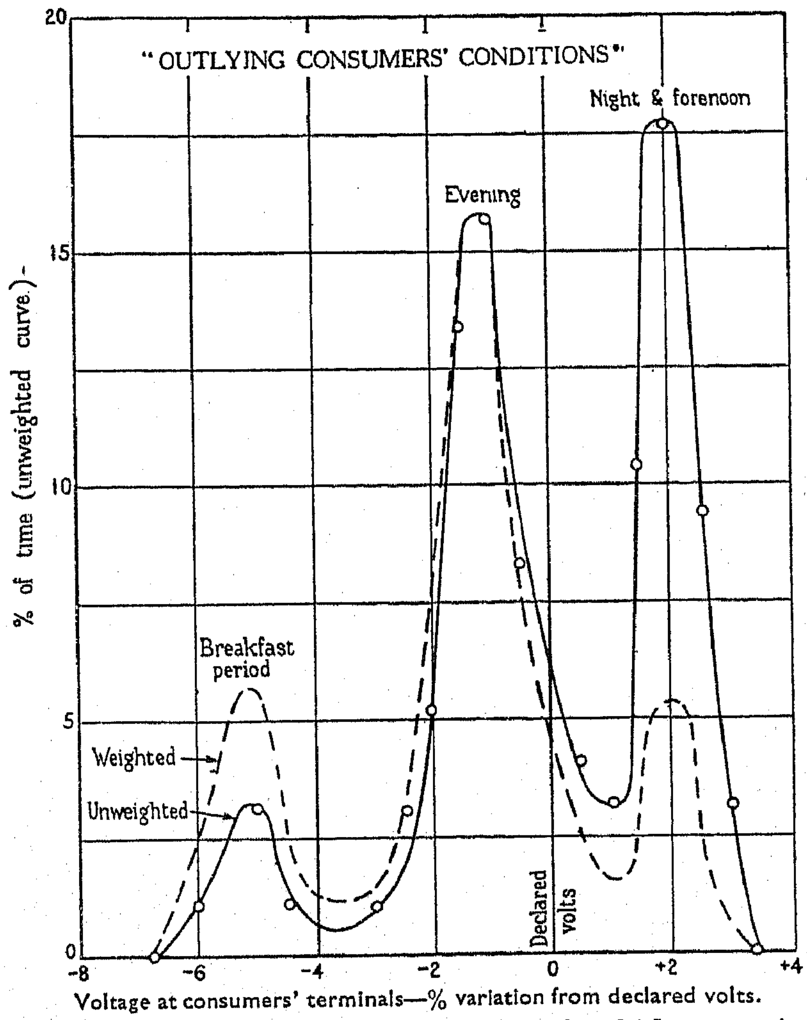

FIG. 4.—Voltage distribution with time for 24-hour period. Tail-end consumer during January. Small country town supplied through 6 miles of 20-kV overhead line. No local regulation. Curve is for a private house 1 400 yards from local substation and shows conditions for two consumers out of 535.

If, instead of taking 1-minute values, the average value over, say, 15 minutes is taken, the peaks and valleys

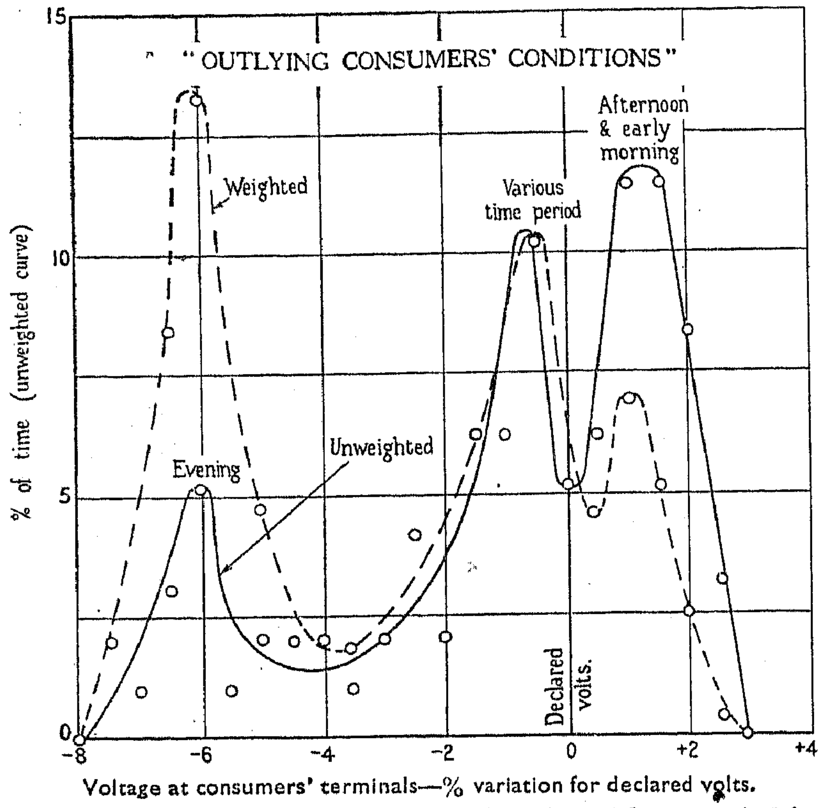

FIG. 5.—Voltage distribution with time for 24-hour period for a consumer 1 000 yards from local sub-station and shows conditions for 40 consumers out of total of 321. Colliery village supplied from a 5·5-kV distribution system. No local regulation.

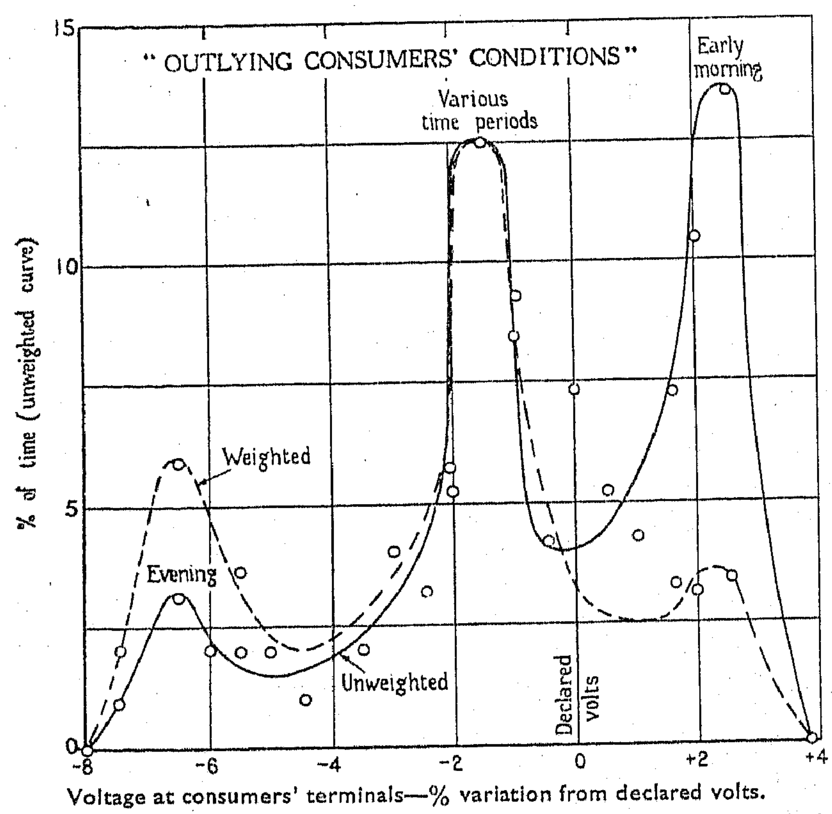

FIG. 6.—Voltage distribution with time for 24-hour period during November for a private house 1 300 yards from the local substation, and shows conditions for 5 consumers out of total of 259. Residential village supplied through 7 miles of 11-kV overhead line. No local regulation.

on the voltage and current charts will be reduced in magnitude, and this will reduce the dispersion of the voltage variation as shown in Fig. 7.

The voltage at any particular time is determined by the load and also by the regulation of the system. As

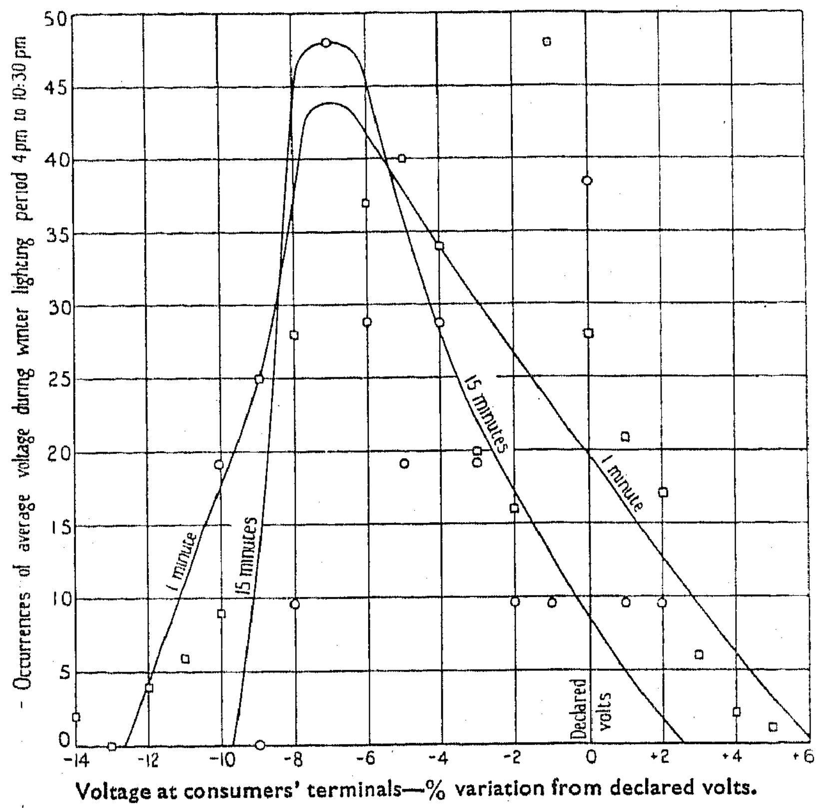

FIG. 7.—Averages calculated over consecutive one-minute intervals give a wider dispersion to the voltage/time distribution curve than when the averages are calculated over consecutive 15-minute periods. Tail-end consumer on a low-voltage overhead system serving a residential estate supplied from local transformer fed through 4 miles of 8 000-V cable. No local regulation.

the latter may lag or lead the load, there are usually several values for feeder load for any specific voltage at the terminals of any consumer. Any change in the distribution of a given load in a network may also cause a change in voltage at a consumer's terminals.

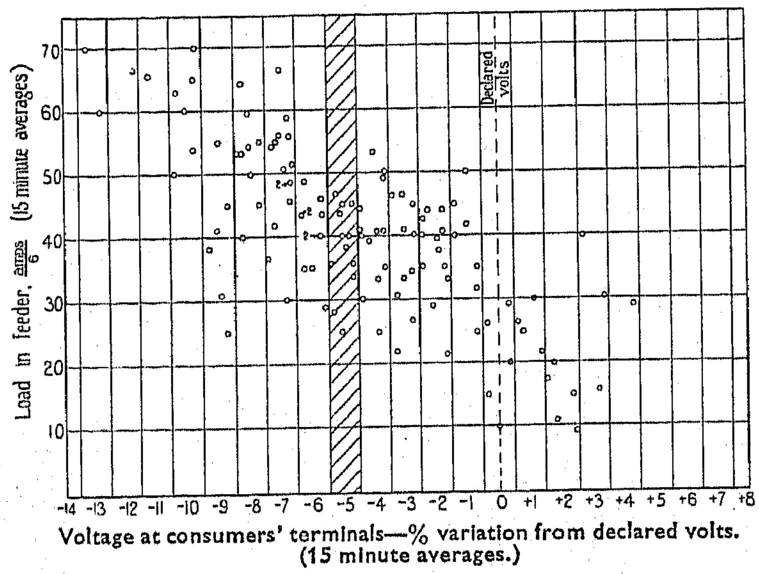

FIG. 8.—Scatter diagram of feeder current and a distant consumer's terminal voltage. Use period only. (Two days 7.30 a.m. to 10.30 p.m.)

The voltage time curves shown in the above-mentioned figures have the character of normal probability curves, but have points of difference which will now be considered. Attention is directed to the long tail on the low-voltage side; this is of small area and at first sight

might be considered unimportant; further consideration suggested that these low-voltage values are likely to occur at times of heavy load, and consequently this part of the curve might represent a large part of the power supplied to the consumer. It therefore became evident that to ascertain the bearing of the distribution curve on the business done, it is necessary to weight the curve so as to show the distribution of voltage in relation to the amount of power supplied.

(*f*) *Voltage Distribution with Time Weighted for Load.*

To save labour, the averages of $\frac{1}{4}$-hour periods, instead of 1-minute periods, were employed. The average values thus obtained for consumers' terminal volts and feeder loads were plotted as shown in Fig. 8. The curves for voltage distribution with load and time were obtained from the scattered points as follows:—

The voltage scale was divided into steps each of 1 per cent voltage variation as, for example, the step $-4 \cdot 5$ per cent to $-5 \cdot 5$ per cent, Fig. 8; the average load for each step was calculated, i.e. 38 for the 12 loads recorded for the example and the curve connecting the average load for the selected voltages, plotted as in Fig. 9.

The unweighted consumers' voltage curve was obtained by plotting the number of occurrences, i.e. 12 in the above example, for each voltage step selected. To weight this curve, its ordinates were multiplied by the corresponding ordinate of the load curve and for convenience the values obtained were reduced in magnitude so as to make the peak of the unweighted and weighted curves of the same height as shown in Fig. 9.

The weighted curve shows the relative amount of power delivered at each voltage, and this is *the important curve in considering the characteristic of the supply given and its effect on the life and efficiency of electrical apparatus.*

(*g*) *Selection of Time of Day.*

The shape of the voltage distribution with time curve will vary with the period selected. This is illustrated by comparing Fig. 9, the "use period" (in this case 7.30 a.m. to 10.30 p.m.), with Fig. 10, the 24-hour period. These records were obtained during the winter, when there was a fairly heavy domestic load all the time that people were up, and were obtained in a district where electricity was not used for street lighting. These particular conditions produce a double-hump curve for the reasons given in Section (*e*).

Fig. 11 shows the three curves for the same consumer when the analysis is confined to the lighting period, viz. 4 p.m. to 10.30 p.m. The percentage change in load being smaller, the effect of weighting is less marked than in the case of a period, e.g. 24 hours, when there is a considerable percentage change in the load. Other examples of weighting various voltage curves are given in Figs. 4, 5, and 6.

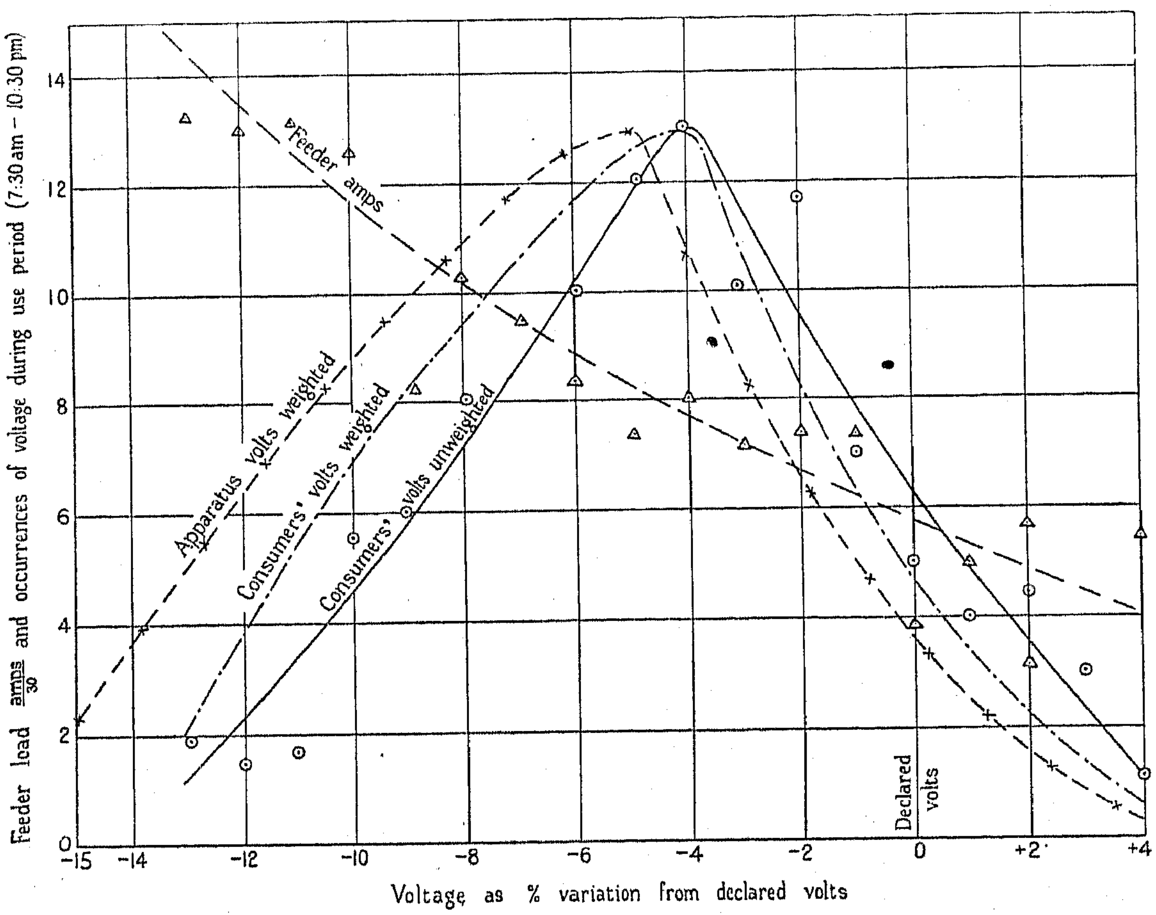

FIG. 9.—Average feeder loads for assumed average voltages and effect of weighting for load the use period distribution curve for voltage at:—

(*a*) Consumers' terminals.
(*b*) Apparatus terminals. (Drop in consumers' wiring at max. load assumed to be 2 per cent.)

(h) Selection of Period of Year.

The records obtained during the summer period do not show as great a voltage variation as the records obtained during the winter months. Compare, for example, Figs. 2 and 3.

As the records obtained on System (iii) were confined to the summer period, no curves from this system are included in the report.

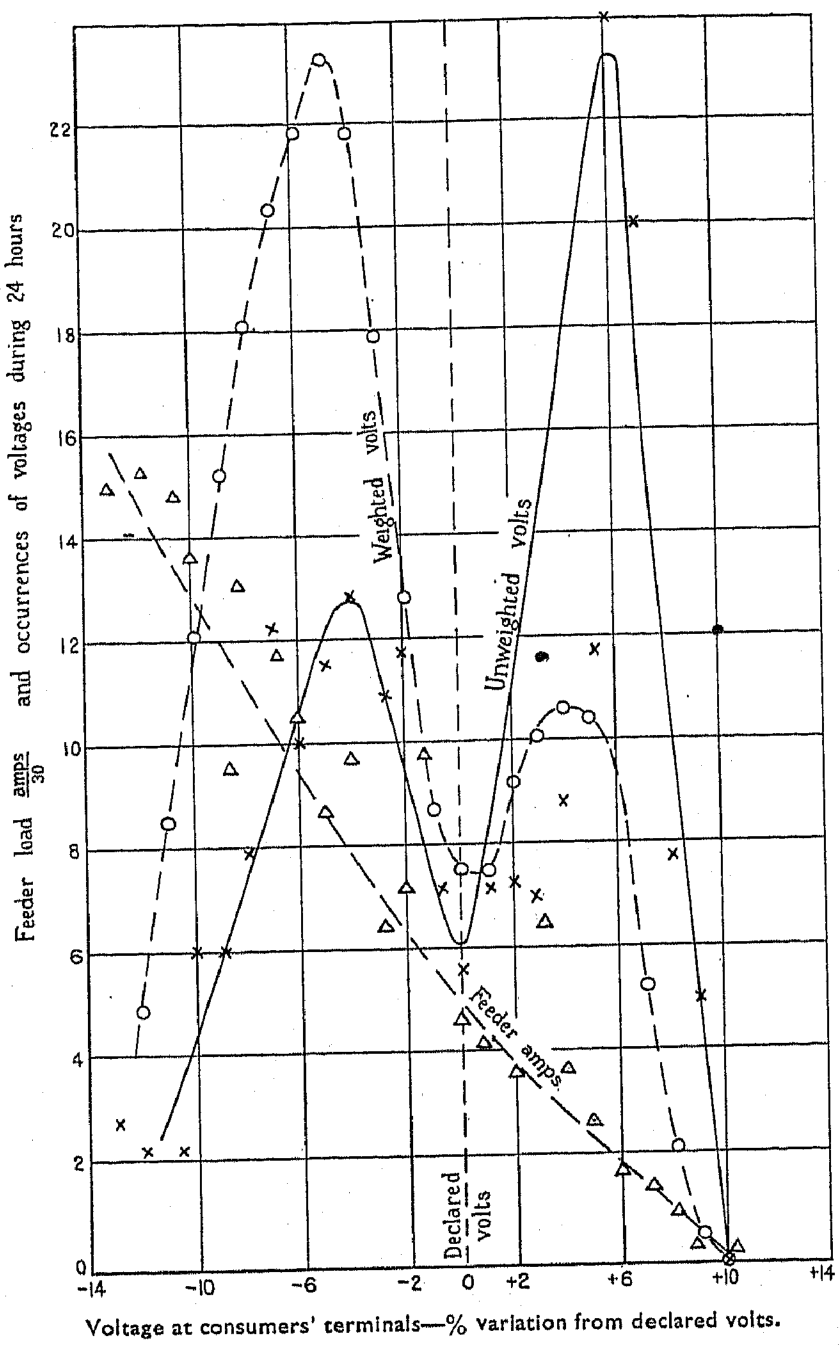

FIG. 10.—Average feeder loads for assumed average voltages and effect of weighting for load the 24-hour period distribution curve for a tail-end consumer during December on a low-voltage overhead distribution system fed from local transformer supplied through 4 miles of 8 000-V cable. No local regulation.

(j) Selection of Unit Time for Analysis.

From Fig. 7 it will be seen that taking 1-minute readings instead of the average during 15 minutes, increases the total variation recorded, the increase in this case being of the order of 35 per cent. If for the analysis the time period was selected at less than 1 minute the curves would show a still wider dispersion.

In drafting regulations for voltage variation, it is clearly necessary to consider what period is appropriate for the purpose in view and also how the voltage should be recorded. These features are referred to again in Section III (*e*).

(k) The Load taken by an Individual Consumer.

The service given to the individual consumer can be precisely assessed only by the use of a weighted curve based on observations on the individual consumer's premises, but in general it is, of course, impracticable to adjust a general supply to the idiosyncracies of individual consumer's demand.

Recognizing, however, that different classes of consumer take different types of load, it may be worth while to study their proper weighted curves in cases where a material departure from average may be expected in one or another part of a system.

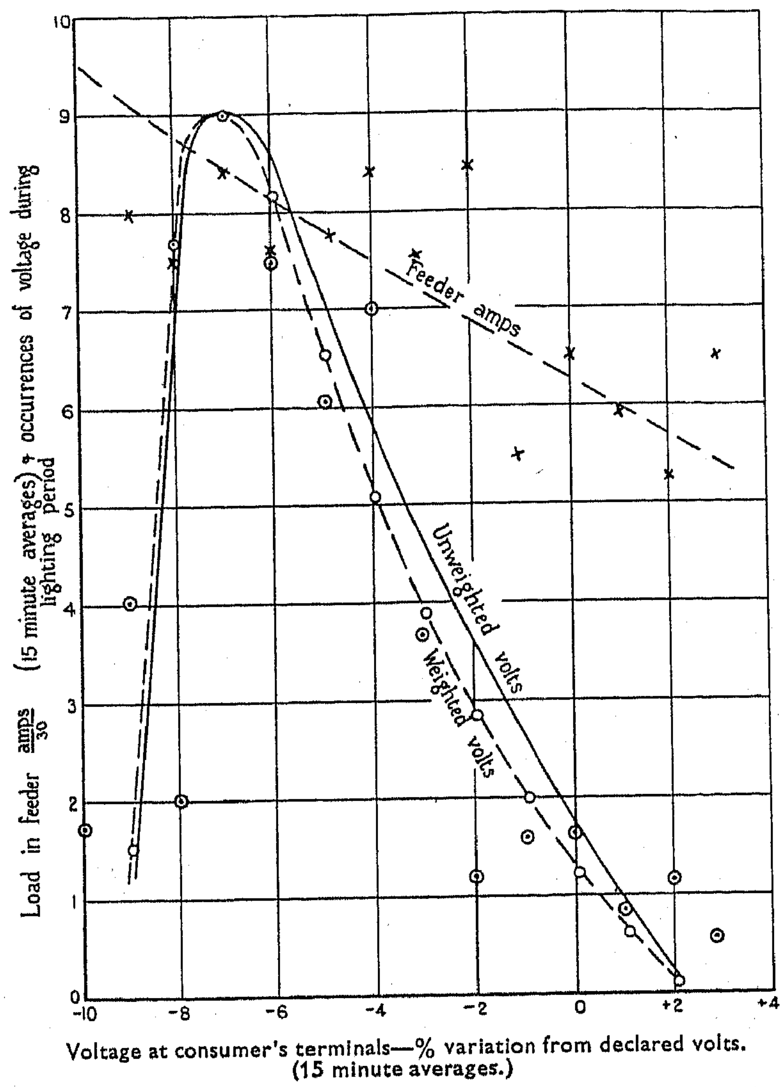

FIG. 11.—Average feeder loads for assumed average voltages and effect of weighting the lighting period (4 p.m. to 10.30 p.m., December) for a tail-end consumer on a low-voltage overhead system supplied from local transformer fed through 4 miles of 8 000-V cable. No local regulation.

(l) Drop in Consumers' Wiring.

Clause 74 in the 9th Edition of the I.E.E. Regulations for the Electrical Equipment of Buildings permitted a voltage-drop from consumers' terminals to the apparatus terminals of 1 volt + 3 per cent of the declared supply

voltage, or practically 8 volts or $3\frac{1}{2}$ per cent on a 230-V system.

In the latest (the 10th) edition, this has been reduced to 1 volt + 2 per cent, that is, 5·6 volts, or approximately $2\frac{1}{2}$ per cent on a 230-V system.

TABLE 1.

Results of Tests to Determine the Drop in Voltage in Consumers' Wiring when Taking Maximum Normal Load.

Consumer	Maximum load recorded, amperes	Maximum voltage-drop in wiring, expressed as percentage of declared voltage
A	28	1·0
B	27·5	2·5
C	30	2·5
D	12·5	1·0
E	159	2·5
F	53	0·8
G	56	1·4
H	108	4·25
Average	—	2·0

In some of the experimental investigations, recording voltmeters were connected at the terminals of apparatus as well as at the consumers' terminals. Voltage-drops were thus obtained for various loads measured by a recording ammeter in the consumers' mains. The results of these tests are summarized in Table 1.

These observations suggest that under maximum normal load conditions the drop in a consumer's wiring may be appreciable and material. Assuming as a rough approximation that the drop at lower loads is proportional to the load, the curve for voltage at consumers' terminals can be translated into a curve for voltage at the terminals of the apparatus, and this curve can then be weighted for load as shown for example by the weighted apparatus voltage curve in Fig. 9, thus representing the real supply, as the consumer is really concerned with supply to the apparatus he uses, not to his "terminals."

(m) *Increase of Revenue by Better Regulation.*

The weighted curves show that a considerable proportion of the power is delivered at a low voltage, and it may be noted that this causes a material loss of revenue. The magnitude of the loss will be influenced by the following:—

Radiators, Cookers, etc.—As the resistance wire used has a relatively small temperature coefficient of resistance, the percentage decrease in energy will be approximately twice the percentage decrease in voltage for changes of the order under consideration.

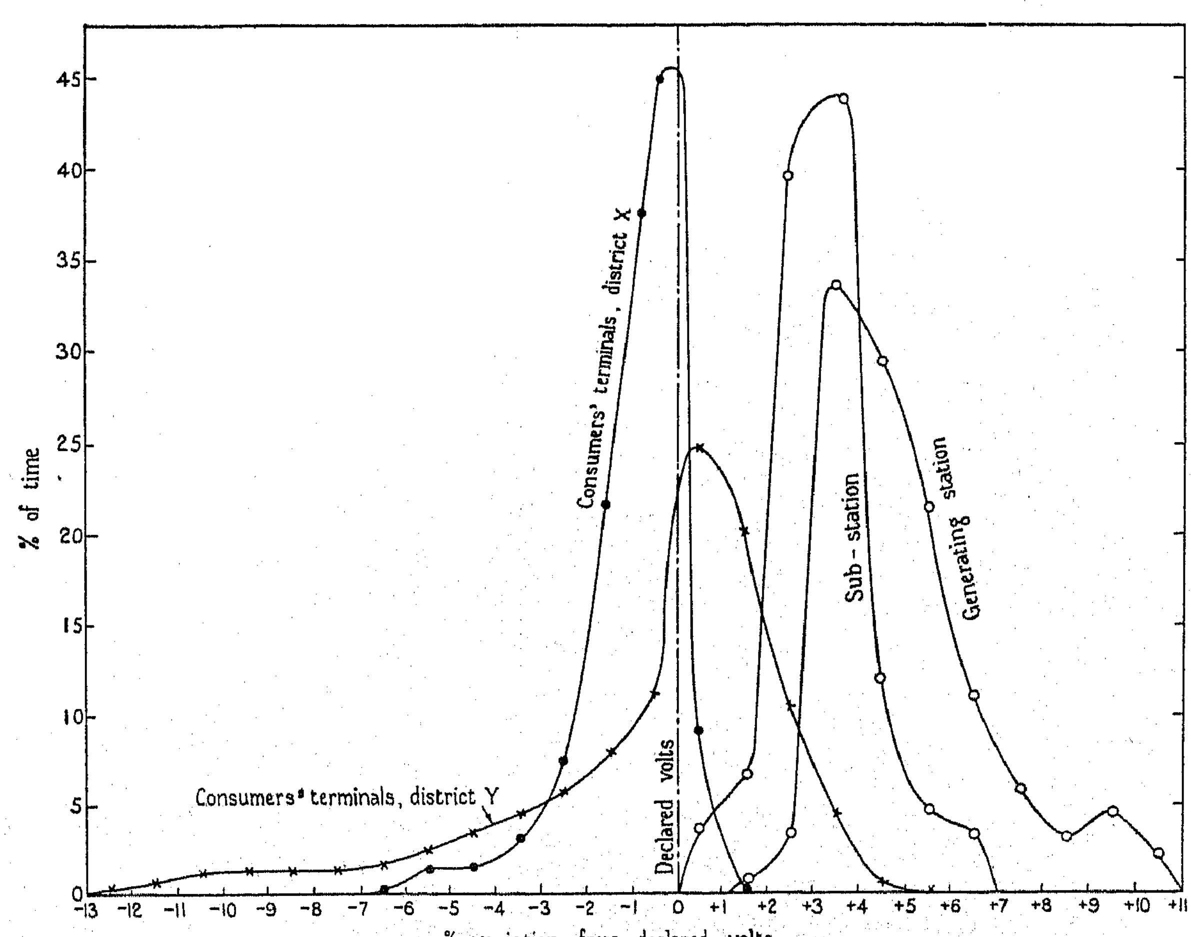

FIG. 12.—Voltage distribution with time. (A London system.) 24-hour period. Districts X and Y are subject to different fixed transformer boosts.

Tungsten-Filament Lamps.—Due to the relatively high temperature coefficient of tungsten, the percentage decrease in energy, or increase when the voltage is raised, is about 1·5 times the percentage change in voltage.

Motors.—The energy will be independent of voltage.

Revenue.—The effect of the change in energy consumed on the revenue of the supply company will be influenced by the tariff.

Compensating Action.—To some extent the lower rate of energy consumption due to low voltage may be compensated by the consumer, e.g. switching on more lamps, water heaters in use for a longer time. The increase in energy resulting from an increase in consumers' voltage may be compensated by the consumer taking steps to reduce his bill to a budgeted amount. (See *Electrical World*, 24th December, 1932, p. 856; also comments on this paper in Messrs. Kidd and Carr's paper referred to in the next paragraph.)

Results Recorded.—In the reply to discussion on their paper, Messrs. Kidd and Carr† state that their records (Manchester Corporation) indicated that in residential districts the energy consumed had increased by between 5 and 10 per cent after the introduction of voltage control.

(*n*) *Some Miscellaneous Observations.*

At an early stage in the experimental investigation voltage records were obtained at various points on certain London systems. The voltage distribution obtained on one of those systems is shown in Fig. 12.

† *Journal I.E.E.*, 1934, vol. 74, p. 319.

II. Effect of Voltage Variation on Electrical Apparatus.

(*a*) *Introduction.*

As the result of inquiries of manufacturers and others a quantity of information has been collected bearing upon the performance which may be expected of electrical apparatus subject to a varying voltage supply and covering also variations in the products themselves and their effects. This information is summarized in the following pages.

Table 2.*

Under- and Over-Voltages at Terminals of Apparatus which might Occur in Practice without the Permissible Limits being Exceeded.

Cause of difference in voltage	Difference between voltage required and voltage available			
	Name plate 200/220 V		Name plate 220/240 V	
	V	%	V	%
6 per cent permissible voltage drop at consumers' terminals	− 12	− 5·46	13·2	− 5·5
2 per cent + 1 volt permissible drop in consumers' wiring..	− 5	− 2·19	5·5	− 2·18
Sales + manufacturers' tolerances	− 20	− 9·1	20	− 8·35
Total under-voltage difference	− 37	− 16·75	40·8	− 16·03
6 per cent permissible voltage rise at consumers' terminals	+ 13·2	+ 6·6	14·4	+ 6·55
Assume no drop in consumers' wiring	—	—	—	—
Sales + manufacturers' tolerances	+ 20	+ 10	+ 20	+ 9·1
Total over-voltage difference	33·2	+ 16·6	+ 34·4	+ 15·65

* The values in this table assume for the under-voltage conditions that apparatus which should receive 220 volts and 240 volts respectively is used on a declared voltage of 200 and 220 volts respectively, and for the over-voltage condition the apparatus which should receive 200 and 220 volts respectively is used on a declared voltage of 220 and 240 volts respectively.

(*b*) *Voltage Variations which may be Encountered.*

(i) The Electricity Supply Regulations, 1934, permit the supply at a consumer's terminals to vary by ± 6 per cent from the declared voltage.

(ii) The Regulations for the Electrical Equipment of Buildings permit a voltage drop from the consumer's terminals to the terminals of the apparatus of 1 volt + 2 per cent of the declared voltage.

(iii) Low-tension supplies in this country vary from 200 to 250 volts. To cover this range in two steps the apparatus will have a sales tolerance of ± 5 per cent from its design voltage.

(iv) With most electrical apparatus a manufacturing tolerance of ± 5 per cent on the design voltage is permitted.

For a declared voltage of 230 the statutory limits

become in effect, from (i) and (ii) above, + 6 per cent to − 8½ per cent.

The sales and manufacturing limits may result in some units being used on a circuit, the voltage of which differs by ± 10 per cent from the voltage the particular unit should receive.

Assuming the above limits are not exceeded, the apparatus might possibly be used under voltage conditions which differ from its correct voltage by the extent shown in Table 2.

In practice it is most improbable that all of the tolerances will occur in the same direction at the same time, as has been assumed in the table. The average departure

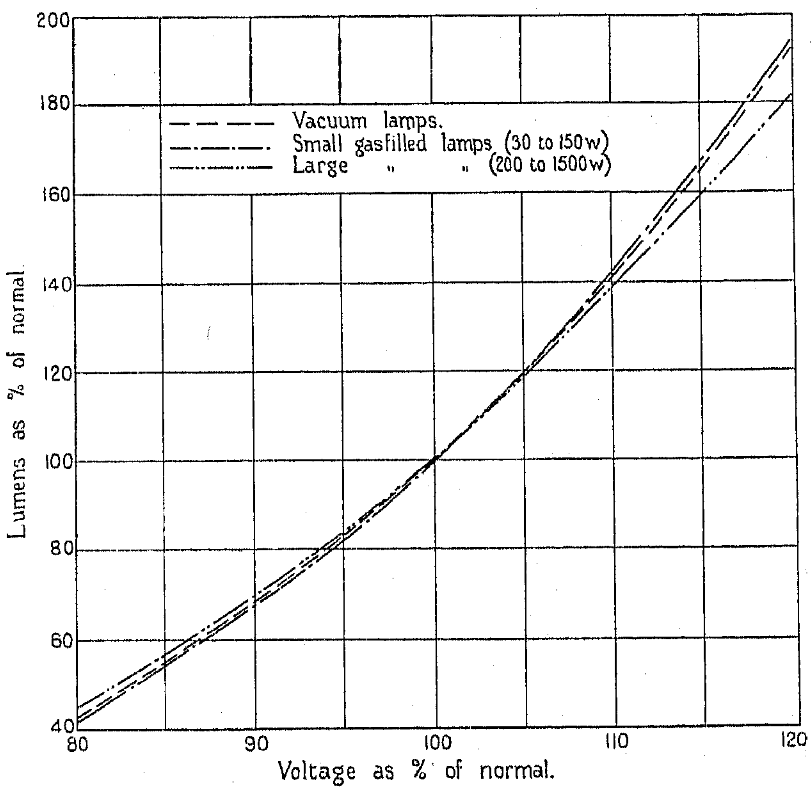

FIG. 13.—Effect of voltage on the light from vacuum and gas-filled lamps.

in particular systems is likely to reach 2½ per cent and will considerably exceed this figure in individual cases.

Part I of the report furnishes representative examples of the distribution of voltage during the time periods when various types of electrical apparatus are in use and thus renders it possible to examine the effect of voltage variation in some detail. This is done in the sections following.

(c) *Lamps.*

The life and efficiency of lamps are influenced by voltage to a greater degree than most other electrical equipment which is used on a large scale.

(i) *Vacuum and Gas-Filled Lamps.*—Fig. 13 shows the effect of voltage on lumens and Fig. 14 on life of modern lamps of these types. Fig. 15 shows voltage/time curves for lighting periods obtained from the experimental investigation, and Table 3 their effect on life and light of small gas-filled lamps.

Consideration of Table 3 led to the exploration of effect on life and light of a variation *per se*, and also of departures of average or weighted average voltage from

TABLE 3.

Average Effect on Lumens and Life of Small Gas-Filled Lamps of Voltage Distribution Curves in Fig. 15.

Curve in Fig. 15	Average weighted voltage as percentage of declared voltage	Corresponding lumens, per cent	Corresponding life, per cent
A	− 5·14	75·6	254
B	+ 1·5	105·0	81
C	− 3·5	89	155·3
D	− 6	76·2	244
E	+ 2·5	110·8	72
F	0	99·6	103·6

the declared voltage. While the curves in Figs. 13 and 14 show that both life and lumens are highly sensitive to declared voltage, it does not follow that bad variation *per se* shows any disadvantage on the average light and

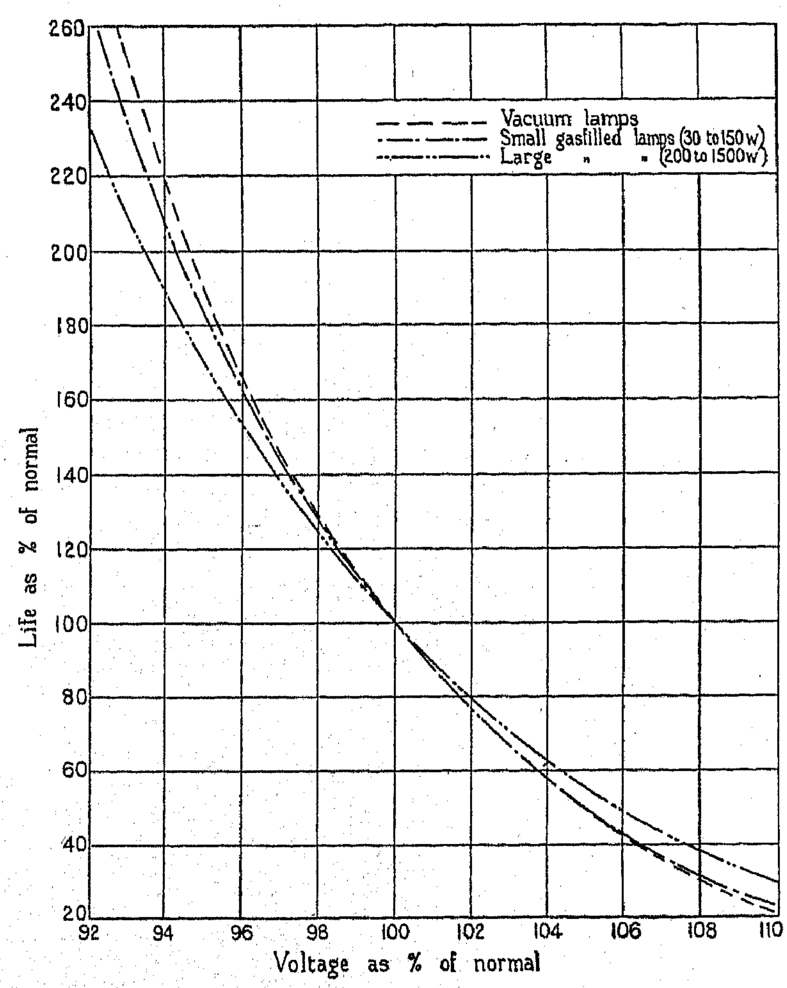

FIG. 14.—Effect of voltage on the life of vacuum and gas-filled lamps.

life. As a starting point it was assumed that a normal probability curve was weighted for load. (See Curve F, Fig. 15.)

Assuming that the effect on life, also on lumens, shown in Figs. 13 and 14, are additive to give the total

average effect, the results of calculation on the symmetrical Curve F are recorded in the first part of Table 4. These results show that if the declared voltage is arranged to give the standard average lumens there is a small increase in life, the increase being greater the worse the regulation.

As a symmetrical curve is not met with in practice, examination was then made of unsymmetrical curves having tails on the right as Curve A, Fig. 15, and on the left as Curve E, Fig. 15. It is found in each case that the results are of the same character.

From the above the following deductions are made:—

(1) From the standpoint of average results on life and light there is no objection to variation *per se*.
(2) The objection to variation *per se* is the variation in the light, viz. $\pm$ 3·6 per cent per 1 per cent variation in voltage, corresponding to a total variation in light of + 22 per cent to − 31 per cent for + 6 per cent and − 8½ per cent voltage respectively.
(3) Both light and life may be sensibly affected if the *average* voltage is not correctly declared.
(4) Declared voltage should preferably be related to the mean voltage of the voltage curve taken over the lighting period. (The analyses made in Part I of the report show that the weighted and unweighted curves for the lighting period do not differ greatly, although there may be considerable difference if longer time periods are taken into account.)
(5) The above suggests the importance of declaring the voltage correctly for any given distribution system or section.

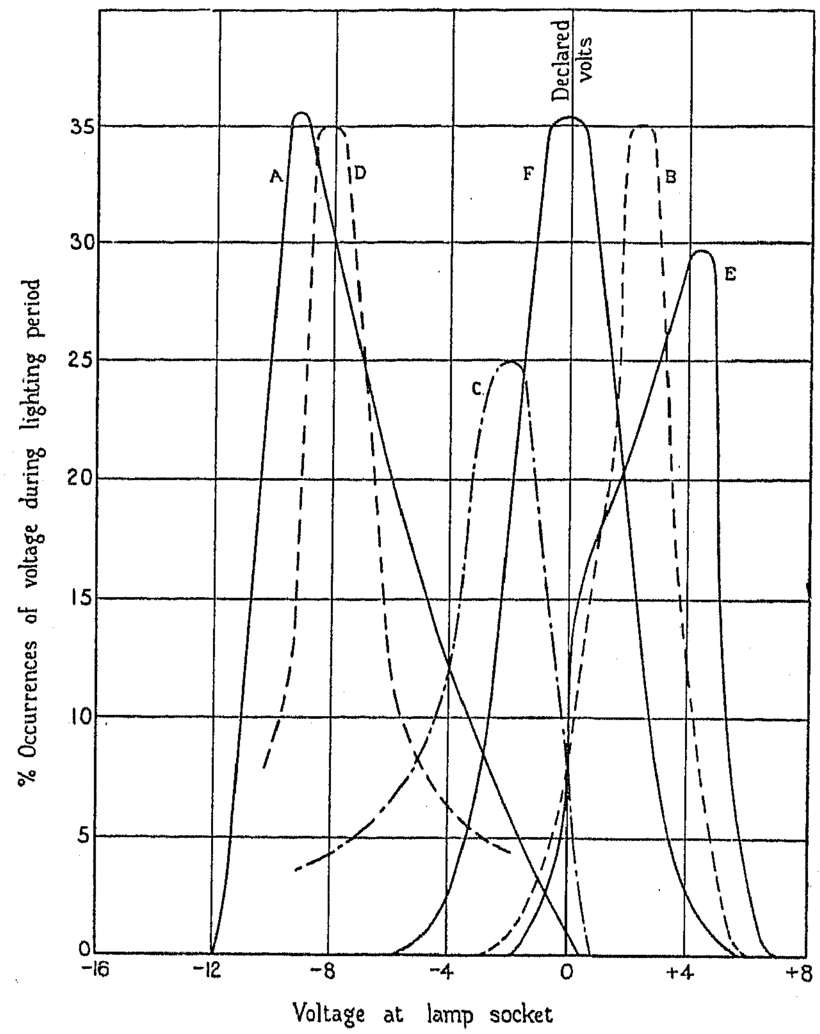

FIG. 15.—Voltage distribution with time. Lighting period during winter.

A. System (*b*) (iv).
B. System (*b*) (ii).
C. System (*b*) (ii).
D. System (*b*) (i).
E. System (*b*) (i).
F. System (*b*) (ii).

TABLE 4.

Average Effect on Lumens and Life of Small Gas-Filled Lamps of the Voltage-Distribution Curves Mentioned.

Case	Voltage spread	Mean voltage as percentage departure from declared	Corresponding average lumens as percentage of normal	Corresponding average life as percentage of normal	Percentage gain or loss in— Lumens	Life*
			Symmetrical (Curve F, Fig. 15):			
1	+ 3 − 3	0	99·5	101·5	− 0·5	+ 1·5
2	+ 6 − 6	0	99·6	103·6	− 0·4	+ 3·6
3	+ 12 − 12	0	100·0	110·7	0	+ 10·7
4	+ 7 − 5	+ 1	103·4	91·7	+ 3·4	− 8·3
5	+ 8 − 4	+ 2	108·1	81·2	+ 8·1	− 18·8
6	+ 6·32 − 5·68	+ 0·325	101·18	100	+ 1·18	0
			Unsymmetrical. Tail on Right (Curve A, Fig. 15):			
7	+ 6 − 6	0	95·5	123·5	− 0·5	+ 23·5
8	+ 9 − 3	+ 3	106·6	84·7	+ 6·6	− 15·3
9	+ 7·53 − 4·47	+ 1·53	101·0	100	+ 1·0	0
			Unsymmetrical. Tail on Left (Curve E, Fig. 15):			
10	+ 6 − 6	0	102	98·6	+ 2·0	− 1·4
11	+ 4½ − 4½	0	101	98·7	+ 1·0	− 1·3
12	+ 5·9 − 6·1	− 0·1	101·5	100	+ 1·5	0

Normal life 1 000 hours. B.S.S. No. 161.

(ii) *Electric Discharge Lamps.*—The nature of these lamps is such that one has to consider starting characteristics, steady characteristics, and instantaneous characteristics. The effect of over- and under-voltage is shown in Table 5.

TABLE 5.

Effect of Over- and Under-Voltage on High-Pressure Mercury Discharge Lamps.

Characteristic	Effect of—	
	Over-voltage	Under-voltage
Starting	Little effect. May reduce life slightly	Lamp may not start if more than 20 to 25 volts below the rated value of the lamp voltage
Steady	Efficiency and life not affected quite as much as tungsten lamps. Percentage change in lumens for 1 per cent change in volts = 3·5 for discharge lamp and 3·9 for tungsten lamp	
Instantaneous ..	Sudden upward rise for a very short time can be permitted	Sudden drop of 25 volts or more *may* extinguish the lamp, which might then require 5 to 10 minutes to re-strike

NOTE.—As discharge lamps are usually run in series with a tapped choke an adjustment can be made for a permanent over- or under-voltage in the supply.

(*d*) *Electric Heating and Cooking Apparatus.*

From the point of view of the effect of over- and under-voltage, these fall naturally into the following two classes:—

(i) *Apparatus in which the Working Temperature does not represent the Limiting Factor.*—To allow for the various supply voltages referred to in paragraph (*b*) (iii) above, it is customary for such apparatus as irons, kettles, immersion heaters, etc., to be designed so that even at the maximum rated voltage the temperature of the heating unit will be such as to give a long life to the element. With this type of apparatus it is usual to find the name plate marked for a fairly wide sales range such as 200/220, 220/250 volts. (Universal-voltage irons are supplied for 100 to 125 and from 200 to 250 volts.)

A voltage variation of ± 6 per cent would correspond to ± 12 per cent in heat or time which cannot be considered important, but between − 6 per cent and the possible under-voltage of 16 per cent indicated in Table 2 there is a wide range in which the operation of the apparatus must be considered unsatisfactory.

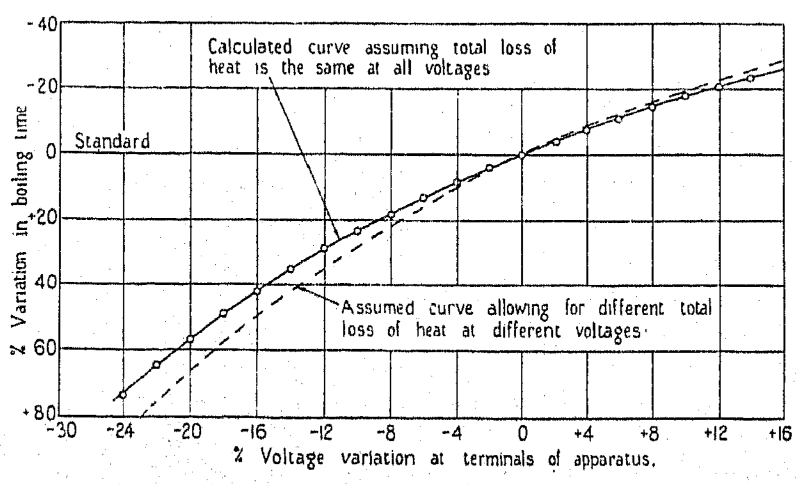

FIG. 16.—Effect of under- and over-voltage on boiling time of kettles, etc. Designed for 230 volts.

The full-line curve in Fig. 16 shows the effect of under-voltage on the boiling time of electrical apparatus. If one takes into account the lower efficiency, due to more total heat being lost during a longer boiling time, the effect will be as shown by the dotted curve in Fig. 16, which shows an increase in boiling time of approximately 50 per cent for an under-voltage of 16 per cent.

Due to the elements being designed to run at a relatively low temperature, their life will not be seriously reduced on any over-voltage likely to be encountered.

(ii) *Apparatus in which the Working Temperature represents the Limiting Factor.*—This class includes radiant heaters as fires, grillers, toasters, etc.; also all types of hotplates or boiling rings, ovens, etc. As the designer must run the heating unit at about its maximum and has to provide for a permissible ± 6 per cent voltage variation, he has no margin for manufacturing and sales tolerance. Consequently more care has to be taken in manufacture and the name plate is usually marked for a fixed voltage, designs being available in 10-volt steps so that one can be selected for any likely declared voltage.

With this class of apparatus the effect of an over-voltage is important. Fig. 17 shows that in the case

of one well-known make of hotplate + 6 per cent in voltage continuously maintained reduces the life by 48 per cent, i.e. by about 1 400 hours assuming a normal life of 3 000 hours.

Electric fires are often selected on the brightness of their glow, and it is not uncommon for elements to be ordered for a lower voltage than that of the circuit on which they are to be used. A 6 per cent over-voltage continuously maintained will reduce the life of the element to approximately half.

A 6 per cent under-voltage corresponds to a reduction in wire temperature of about 40 deg. C., which is quite noticeable in its effect on glow, especially in the case of elements which normally operate at the higher temperatures.

The heating-up and use of electric cookers calls for a relatively large amount of power for a relatively short

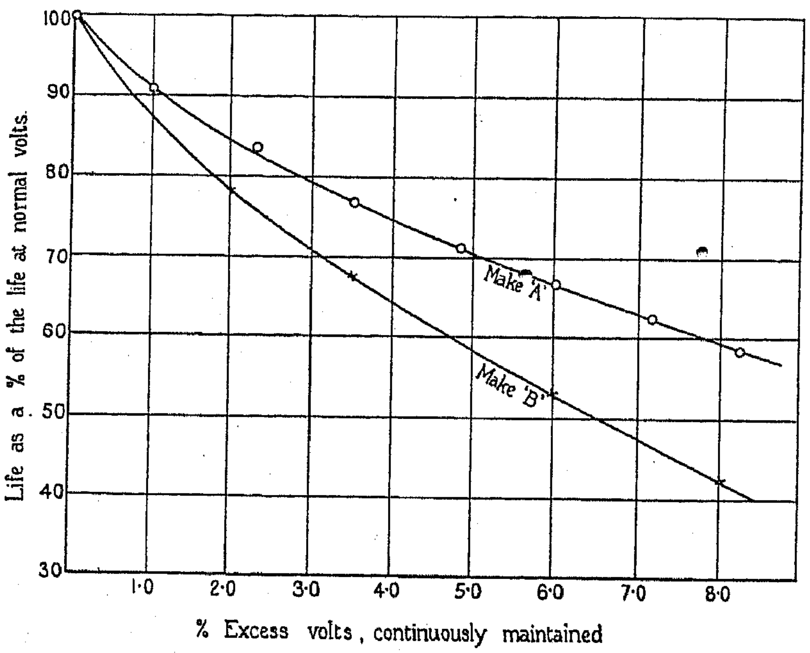

FIG. 17.—Effect of over-voltage on life of enclosed hotplates.

time, and unfortunately its period of use is approximately the same for all consumers.

The heavy load thus taken may cause low voltage at the terminals of distant consumers. The extent to which this can be compensated by raising the supply voltage is limited by the over-voltage at the terminals of consumers near the feeding points.

To obtain the highest efficiency from an electric hotplate, it should be operated at a temperature which is as near as is safe to its fusing temperature. By having to allow for a voltage variation, the designer has to sacrifice the best part of his heating curve. If better regulation was given, the manufacturer could produce a more efficient apparatus and suppliers and users would benefit.

(*e*) *Radio Sets.*

When sold for use on 200/250 volts alternating current, radio sets are usually supplied with tapping points at every 20 volts. In a few cases a 10-volt tapping may be furnished at one end of the winding, thus enabling any 10-volt step to be obtained between the nameplate limits. Within narrow limits the effect of a change in supply voltage is unimportant because the potentials of grid, anode, and cathode, are changed simultaneously. A low voltage may result in overloading and consequent distortion, a high voltage a shorter effective life of valves; also permanent damage to metal-oxide rectifiers, burn-out of smoothing chokes, etc. In general no trouble should be experienced if the voltage variation does not exceed + 6 per cent or − 8½ per cent.

(*f*) *Motors.*

The design and duties of fractional-horsepower motors are usually such as to enable satisfactory operation to be obtained irrespective of voltage changes of the order under consideration.

Larger motors need not be considered, as normally the supply for these would not be taken from the low-tension mains.

(*g*) *Apparatus requiring a Very Steady Voltage.*

Amongst apparatus not used to a large extent there are some which require the maintenance of the voltage within closer limits than ± 6 per cent. To meet these conditions manufacturers can incorporate compensating features or automatic control, but naturally would prefer not to do so on account of the extra cost and additional complication.

X-ray apparatus is an example where voltage compensating equipment often has to be used, but is not always satisfactory when handled by non-electrical people.

Bakers' ovens require a very steady temperature, and should be fitted with thermostat control if the voltage is likely to vary by more than ± 4 per cent.

III. THEORY OF VOLTAGE REGULATION.

(*a*) *Introduction.*

It is shown below that there are many complicated factors entering into the study of voltage variation. But little appears to have been published on the subject hitherto. To enable further consideration to be given to (i) control of voltage variation, (ii) voltage regulation, and (iii) further useful research, it seems desirable to establish an elementary theoretical treatment of the subject. The treatment has been simplified by using certain approximations, the effects of which are examined later. Items are included for completeness which may later be discarded as not worthy of further pursuit.

(*b*) *Effect of Voltage Variation in General.*

It has been shown in Part II that considerable voltage variation *per se* need not result in shortening the life or reducing the *average* efficiency of electrical apparatus, but it can be deduced that in any particular case a variation of the weighted average voltage from the declared voltage must have a proportionate effect both on life and average efficiency.

Good service should then have two characteristics:—

Proposition 1.—The maximum variation of voltage from the declared value should not cause material inconvenience to the consumer while it lasts.

Proposition 2.—The weighted average voltage should not vary from the declared voltage so as to cause material inconvenience by its effect on life or efficiency.

These two features are in some measure independent. They must therefore be the subject of separate study and might be the subject of separate regulations.

As any trouble is felt at the "*consuming points*" rather than at the "*consumers' terminals*," attention must ultimately be focused on the former.

(c) *Factors to be Considered.*

For the purpose of this study, the following factors are recognized and defined:—

Distribution Factor—D.—This is the principal source of variation and is here associated with impedance-drop in the conductors from a single source or distribution centre at which the voltage may be regulated.

Transmission Factor—T.—Where energy is transmitted to one or more distribution centres, it is generally impracticable to provide at the individual centre just that relationship between voltage and load that will give the best local regulation, i.e. that could be obtained if the source were an independent local one. Thus T is superimposed on D.

Transmission may be (*a*) to a few well-placed centres, in which case T should be unimportant, or (*b*) carried out over a large area under greatly varying conditions, in which case T will be more important.

Branching Factor—B.—This may be present with T, with D, or with W (the wiring factor mentioned below). It arises from the branching of feeders or wires which results in a variation of impedance with load as more and more branches are brought into use with increasing load.

Precision Factor—P.—This term is coined to cover an increase of departure of average voltage and of extreme voltage values from the declared voltage due to lack of precision in adjusting the voltage of the supply.

Wiring Factor—W.—This is the variation caused by impedance-drop in consumers' wiring.

Inconformity Factor—I.—This term is applied to variation caused where the load distribution over the 24 hours differs from the average. It may apply to a consumer or to a district fed in parallel with others.

Manufacturing and Selling Tolerance Factors—M and S.—This has the same effect as voltage variation and is superimposed on it as it leads to disconformity between the applied voltage and that which would give the expected performance with the individual article.

(d) *Voltage Variation and Regulation.*

The above factors are now considered in some detail, both as to their effect on voltage variation and in relation to regulation and regulations.

(i) *Distribution Factor—D.*—Fig. 18 illustrates the most elementary distribution. The voltage at the source and throughout the area is uniform at no load, and this is the declared voltage. At full load, the voltage is raised at the source and the extreme drop is found at the remote end. As a first approximation, a straight-line relationship is assumed to represent the voltage supply to consumers at different distances from the source. At half load the voltage variation is assumed to be halved.

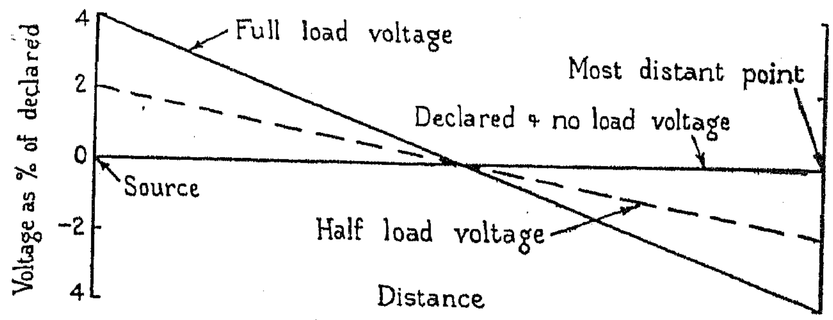

FIG. 18.—Elementary voltage distribution with distance from source, assuming maximum variation = ± 4 per cent.

Fig. 19 shows the percentage departure of the average from the declared voltage, based on an assumed load distribution curve of triangular form. The departure will, of course, vary with the distribution of load.

For a 4 per cent maximum variation it will be seen that the maximum departure is 2 per cent and the average is 1 per cent.

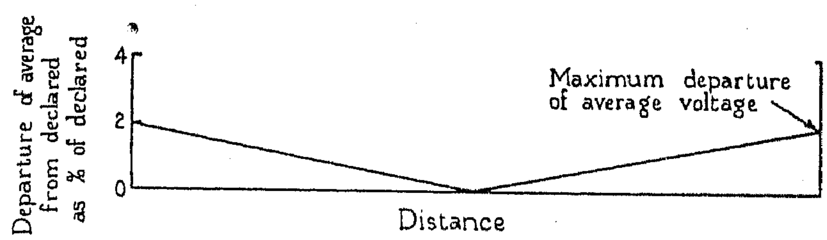

FIG. 19.—From Fig. 18 the maximum departure of the average voltage is 2 per cent and the mean departure of the average voltage is 1 per cent.

(ii) *Branching Factor—B.*—All the curves showing variation of voltage with distance have, so far, been drawn as straight lines. Owing, however, to the branching of the mains and further branching after consumers' terminals have been passed, the resistance between the source and the consuming points, in fact, falls with increase of load. Thus the voltage at half load at the source must be raised above half the maximum value and the half-load curve will cross the zero-load curve at a point further from the source than does the full-load curve, as indicated in Fig. 20. The corre-

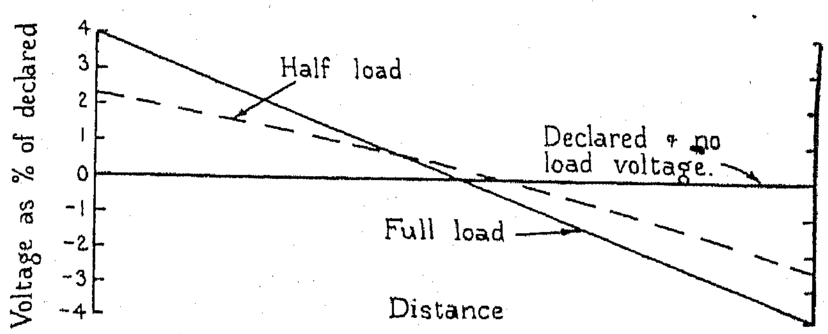

FIG. 20.—Showing effect of branching of mains and consumer's wiring (maximum variation ± 4 per cent).

sponding departure of average voltage is given in Fig. 21, from which it will be seen that the average departure is increased only from, say, 1·00 to 1·18. This change is based on a reduction of resistance of nearly 20 per cent between half load and full load and is but small.

If the horizontal scale is to be made to represent load distribution, then, as the consumers' area increases roughly as the square of the distance from the source, the straight lines in Figs. 18 to 20 must be replaced by curves such as in Fig. 22, to take into account the distribution of load with distance and the branching

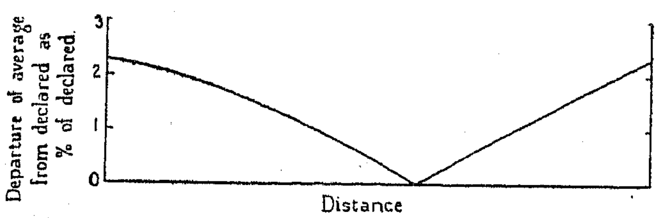

FIG. 21.—Effect of branching on departure of average voltage. Maximum departure of average voltage = 2·3 per cent. Average departure of average voltage = 1·18 per cent approx.

factor. To get, under these conditions, corresponding maximum reductions of maximum variation and departure of average voltage, it is only necessary to adjust the declared values by a small amount depending upon the exact shape of the curve in a particular case.

The branching factor needs no further consideration from the standpoint here discussed.

(iii) *Declaring Two or More Voltages on one System.*—It may readily be shown theoretically that by declaring two voltages on one system, one for near and one for distant consumers, the regulation would be greatly im-

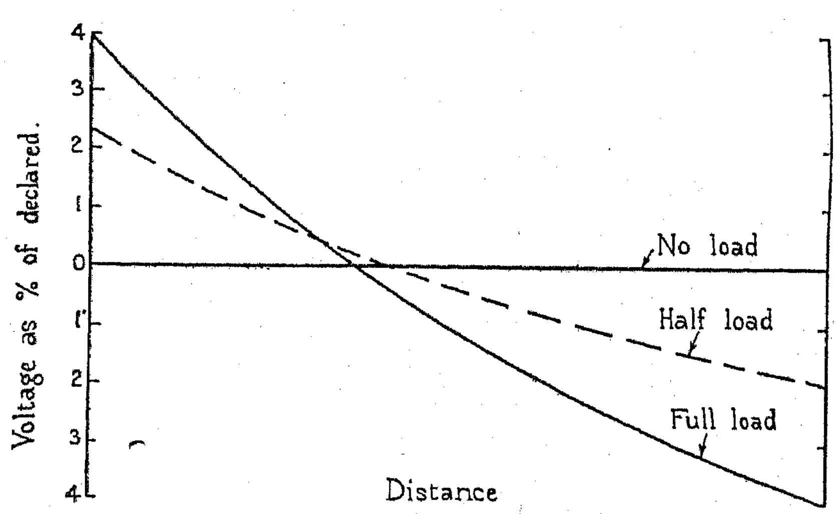

FIG. 22.—Effect of branching factor and a loading distribution approximately proportional to the square of the distance.

proved, or alternatively, the load carried by the feeders might be greatly increased for a given degree of variation, but it is thought that the practical difficulties attached to such a proposal are such that it is not likely to be adopted.

(iv) *Use of Resistances and Regulators in a Distribution System.*—Resistances inserted at the source in the shortest feeders enable the station voltage to be raised to maintain voltage at a distant point without raising voltages unduly at near points. It is cheaper to use a certain amount of resistance rather than heavier conductors throughout. Similarly, some form of boosting device may be used in the longer feeders. The use of such auxiliary devices does not affect the general discussion herein.

(v) *Transmission Factor—T.*—To obtain results on the distribution system such as have been discussed, the voltage at the source must be nicely adjusted to the varying load and the characteristics of the system. This adjustment is disturbed if supply is received from a transmission system. It is for this reason that the regulations governing permissible limits were recently modified, the limits being raised to ± 6 per cent. The additional variation so caused depends upon the extent and complexity of the transmission system and the density of the load distribution in the area covered.

It is easier commercially to give good regulation where the distances are small and the load concentrated, than, for instance, in a rural area fed from an extensive transmission system with mixed load (i.e. large inconformity factor).

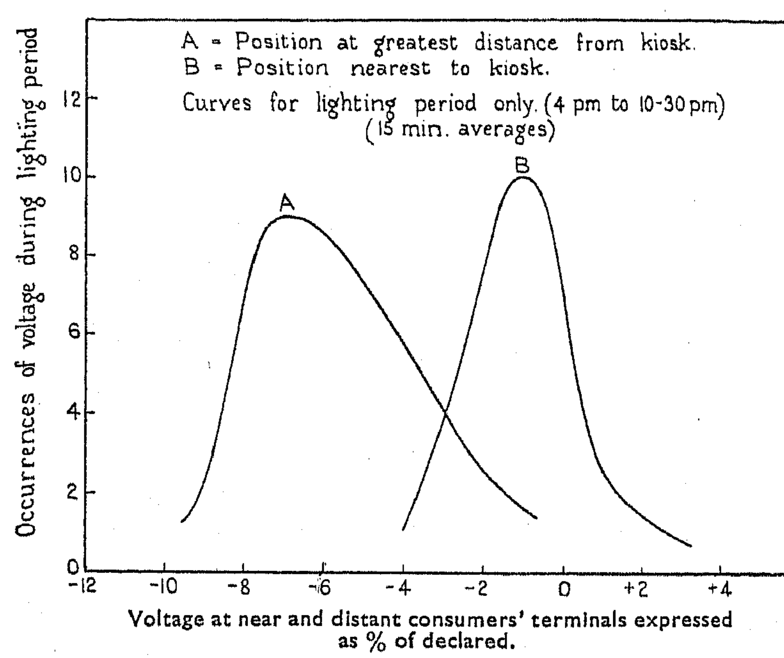

FIG. 23.—Voltage distribution with time for near and distant consumers.

Regulations might fairly require closer limits of variation and of departure of average values in the former than in the latter kind of case.

It is easier commercially also to give good regulation in a fully developed system than in one in the early stages of development when the cost of supplying adequate feeders for outlying load is disproportionally heavy.

(vi) *Precision Factor—P.*—Fig. 23 shows samples of voltage distribution on a certain system, observed at the terminals of a near and of a distant consumer, showing relatively high voltages at the near point as would be expected. It is immediately apparent, however, how much room there is in this case for improvement of both maximum variation and departure from average by greater precision in declaring the voltage or in the adjustment of it to the declared value or values. To come within existing regulations, this supplier will have to add to his feeders unless he takes other steps to make appropriate adjustment. The diagram is, of course, not representative of general practice, neither is it unique.

It clearly illustrates the nature and importance of the precision factor.

(vii) *Wiring Factor—W.*—It is convenient to examine the quality of the service given, by measurement at the consumers' terminals, where control by the supply authority ends, but the consuming point is the important one from the standpoint of the user. It is recognized that there must always be a voltage-drop in the consumers' wiring, thus to obtain the best results the average weighted voltage at the average consumers' terminals should be above the mean weighted voltage by an amount calculated to compensate to the best advantage for this wiring factor. Some regard might be given to the class of business. In small private premises and probably amongst the majority of users in the present day, the average weighted drop would be of the order of 1 per cent or less. There is no evidence available. In an industrial area the average weighted drop might well exceed 2 per cent. If one assumes an all-round value of 1 per cent or more,* then clearly the voltage at consumers' terminals generally should exceed the declared value by this amount.

This result would be secured by the employment of unequal tolerances in the Regulations; for example, by setting the limits at $+ 7\frac{1}{2}$ and $- 4\frac{1}{2}$ instead of $+ 6$ and $- 6$. *There appears to be no justification for equal + and − values.*

The purchaser purchases to a standard voltage, and having regard to the importance of securing that the weighted average voltage at his consuming points should approach this standard value, it is suggested that the supply authority should aim to secure that the average (preferably weighted average) voltage at the consuming points should not vary from a standard value by more than, say, 2 per cent.

It would appear that improved performance could be obtained under regulations allowing even a larger range than $+ 6$ to $- 6$ per cent if the departure of average could be tied at the same time.

Having regard to the magnitude of the wiring factor and the value of securing a correct mean voltage, it is worth considering whether the consumer would not gain more by reducing the drop in his wiring than he would lose through the increased initial outlay. The recent modification of the I.E.E. Wiring Regulations reducing the maximum permissible drop to 2 per cent plus 1 volt will be beneficial.

It is interesting to note that the indications in this section of the report towards an increase of average voltage at consumers' terminals would not only give better service to the user, but would increase the revenue of the supply undertakings by a figure approaching 1 per cent. [See I (*m*) on page 691.]

(viii) *Inconformity Factor—I.*—Apart from the use of feeder resistances and regulators, the supply authority can control voltage distribution only at the source and can thus only secure a certain average quality of voltage supply throughout its distribution area, adapted to the average character of the load. Customers whose demand is different in character from the average must suffer to a corresponding degree. That is to say, if their individual distribution of load throughout the day differs from the average they will require a different weighting curve. Thus if the supply be adapted to give the best average service, some individuals will be receiving too high and others too low a weighted average, according to the nature of their load. This is unavoidable, and can be dealt with only by segregating different districts according to their load characteristics and putting them under independent control.

A consideration of this kind is introduced, not only for theoretical completeness, but because the cumulative effect of all the factors D, T, B, P, W, and I, is so considerable in extreme cases that attention to details, far from being wasted, is indeed important.

(ix) *Manufacturing and Selling Tolerance—M and S.*—The steps between standard rating of, for example, lamps having been well established, this secures a maximum departure of the individual appliance from its ideal rating. With steps of 10 volts or something over 4 per cent of declared voltage, no device should vary from average by more than about 2 per cent. On manufacture by chance such a sorting would produce an *average* variation of about 1 per cent, and if the standard sizes are aimed at the average variation would be less. This variation of 1 per cent, small as it is, is relatively unimportant to the user as compared with a variation of 1 per cent due to any of the factors D to I inclusive, as he purchases many lamps, for example, and what he loses on one below the average, he gains on another above the average.

(*e*) *Time Factor in Measurement of Maximum Variation.*

Section 34 (*b*) of the Electricity Supply Regulations states that the voltage declared shall be constantly maintained, subject to a permissible variation not exceeding 6 per cent above or below the declared voltage, which suggests that the voltage must not at any instant exceed the above limits.

The question arises, what is meant by "instant"? If the period of observation is made too short, the study becomes one of surge phenomena, and clearly this was never intended. Looked at from the other extreme, it might be said that as the effect on certain electrical apparatus such as water heaters, etc., is an average effect, it would be satisfactory to take the average voltage over, say, 5 minutes. The best solution possibly lies between these two limits, but consideration must also be given to the method by which the voltage is to be measured.

In the research carried out by the E.R.A. the voltage was printed on a chart once every 60 seconds, the printing of the dot occupying about 5 seconds, but the needle was free to move for probably less than one second when in contact with the paper. This method, which is extensively used, thus takes account only of variations averaged over something less than 1 second, and unless they last for 60 seconds there is a chance that they may not be recorded.

The movement of a continuous recorder may be damped, but in action the damping is largely controlled by friction between pen and paper and on a sudden movement the ink-flow so lubricates the pen that an overswing is inevitable. The pen, however, returns at

* The average of 2 per cent in Table I on page 691, is, of course, based on a sampling quite inadequate for the present purpose.

once to its proper reading point; thus such overswings are characterized by the feature that the outward and return motions overlap so that the mark made is the width of the ink line, say, about one-fiftieth of an inch.

Examination of the actual charts taken with the tapping recorders referred to above showed at once that it was exceptional to get several points recorded on any one upward or downward change of voltage. Thus it followed that the extreme values of voltage occurring were probably never recorded. Seeing that the pen is free to move on the paper for probably less than one second, the chance is at least 60 to 1 that the absolute maximum or minimum value was missed. We have no information as yet as to the normal rate of change of voltage in the neighbourhood of maximum and minimum peaks, and this requires further investigation.

If it can be agreed that departures from the agreed limits for periods of a minute or two could be tolerated, then with the graphic tapping recorder one would ignore the lowest or highest reading, and a roughly corresponding result would be obtained by ignoring anything lasting about 1½ minutes. With a chart recorder running 1 inch per hour or one month per roll, it would be difficult to recognize a period of 1½ minutes, and there would be objection to speeding up to, say, 3 inches per hour on account of the large amount of paper to be handled.

An alternative course would be to average the extreme values over, say, 5 minutes. This could possibly be done even on a chart running at ½ inch per hour, seeing that precision would not be necessary; it would not be the intention to condemn an undertaking running very near the limit. Such an average could be observed either on a tapping recorder or a continuous recorder.

IV. Summary of Conclusions.

(*a*) A number of normal distribution curves are given of voltage variation with time, roughly picturing the quality of electricity supply from the standpoint of voltage variation [I (*e*) *et seq*.].

(*b*) These distribution curves resemble normal probability curves, but with characteristic differences, which are discussed [I (*e*) *et seq*.].

(*c*) They sometimes show two or more humps, indicating the presence of two or more sets of controlling conditions [I (*e*), (*g*)].

(*d*) Such curves take no account of load, but if weighted according to the average load for given + or − variations of voltage they picture accurately the quality of the supply in relation to the life and efficiency of consumers' lighting, heating, and power plant [I (*f*) *et seq*.].

(*e*) The amount of departure of voltage from normal observed or recorded, depends upon and increases with the shortness of the time intervals over which the voltage values are averaged [I (*j*), III (*e*)].

(*f*) The consumer is interested in the supply at his consuming points, not at his "terminals," and this is affected by the drop in his wiring [I (1), III (*d*) (vii)].

(*g*) The revenue of the supply undertaking is increased by better regulation and especially by avoiding excessive drop of voltage [I (*m*)].

(*h*) The tolerances on voltage regulation, consumers' drop and on sales and manufacturing ratings alone, may together result in apparatus being used at voltages departing roughly 16 per cent from the best values. The average departure on particular systems is likely to reach 2½ per cent [II (*b*), III (*d*) (ix)].

(*j*) With incandescent lamps, voltage variation, *per se*, is not detrimental to the life or average lumens, but departures from the declared voltage of the average or weighted average voltage at the lamp terminals may seriously affect both life and light [II (*c*)].

(*k*) Mercury-vapour discharge lamps are sensitive to voltage-drop on starting-up and are sensitive to sudden fluctuations within limits which require consideration [II (*c*) (ii)].

(*l*) With heating and cooking apparatus, departures of average voltage from normal voltage or any sustained departure from normal voltage may seriously affect the satisfactory performance of the apparatus and in some cases the life also [II (*d*)].

(*m*) Most other apparatus is relatively insensitive, but in exceptional cases special regulation is essential [II (*e*), (*f*), (*g*)].

(*n*) Thus plus and minus tolerances on declared voltages at consumers' premises are mainly important to secure against temporary inconvenience [III (*b*)].

(*o*) From the standpoint of performance, the important feature is the (weighted) average voltage at the consuming points in relation to the declared voltage [III (*b*) and (*d*) (vi)].

(*p*) Many factors enter into voltage variation. Their cumulative effect may be considerable, and serious in individual cases [III (*d*)].

(*q*) Relatively larger departures from declared voltage may reasonably be allowed where (i) voltage variation from a transmission system is superimposed on that due to the distribution system, (ii) the system is extensive and with a mixed load, and (iii) in the early stages of development of an undertaking [III (*d*) (v)].

(*r*) There appears to be no justification for allowing equal + and − tolerances on declared voltage as the drop on consumers' premises acts always in one direction [III (*d*) (vii)].

(*s*) In legislating for tolerances the method of measurement of departure from normal requires consideration, especially in relation to the time factor [III (*e*)].

APPENDIX.

Correlation of Voltage at a Consumer's Terminals with Feeder Load and the Consumer's Load.

If a supply were given to a single consumer from a source maintained at a fixed voltage at the feeding end, there would be a direct relation between the voltage at the consumer's terminals and his load. Consequently an analysis of simultaneous voltage and current records would result in the points, as plotted in Fig. 8, lying in a straight line instead of being scattered over an area.

If, as in the report, one deduced from Fig. 8 the feeder ampere curve, the same curve would result when the array of points in Fig. 8 were averaged, (*a*) vertically, thus giving the average load for an assumed average voltage as in Fig. 9, or (*b*) horizontally, thus giving the average voltage for an assumed average load.

If one takes the other extreme where the voltages at the consumers' terminals are maintained constant for all loads, i.e. perfect regulation, there would be no correlation between the volts and amperes, and the (*a*) and (*b*) curves referred to above would be at right angles.

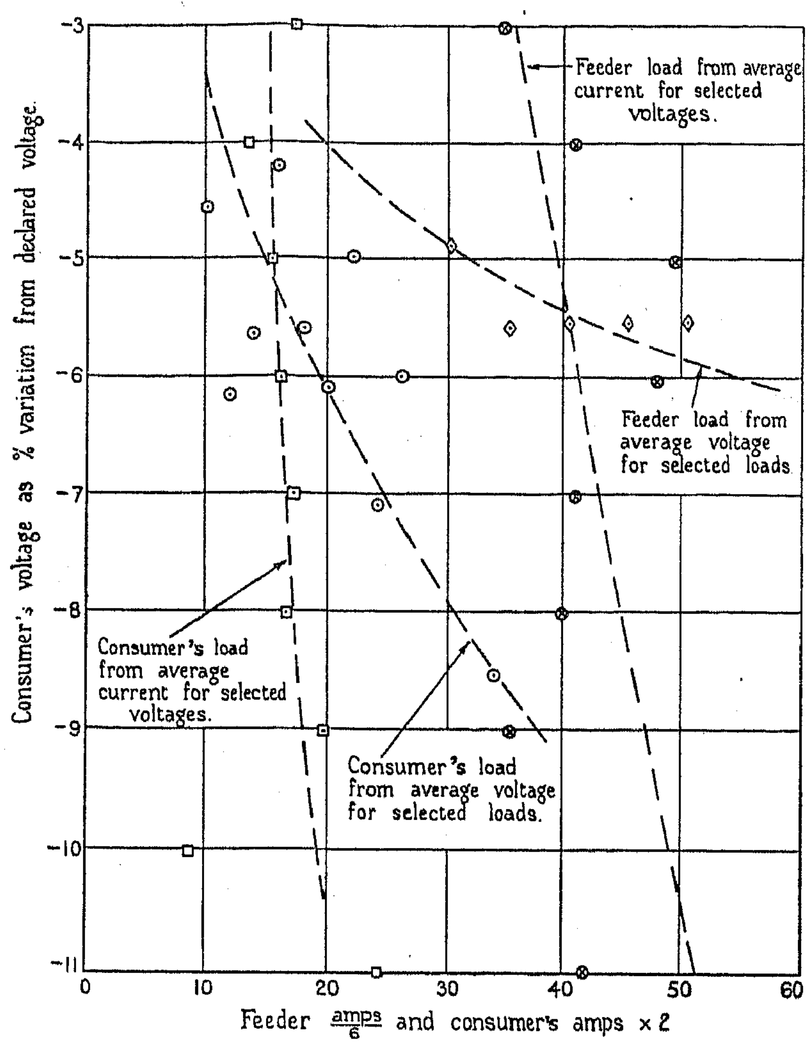

FIG. 24.—Curves showing correlation between a distant consumer's terminal voltage, and (*a*) feeder load, (*b*) the particular consumer's load.

System (*b*) (iv). 8 a.m. to 8 p.m. (Average of 3 days in December.)

Owing to the paralleling of circuits with increase of load, imperfections in regulation, etc., the curves obtained from practical cases will lie between the two extremes considered, and the angle at which the (*a*) and (*b*) curves cross will be an indication of the regulation of the system.

Fig. 24 shows the result of an analysis made of the use period on system (*b*) (iv).

From the above the following deductions can be made:—

(i) In the case of a single unregulated feeder on which the voltage was maintained constant at the feeding end, the two curves would coincide. It should be noted, however, that on a branch system the two curves could not coincide unless the ratio of the loads in all the branches was always the same.

(ii) In the case of perfect regulation, resulting in no voltage variation at any point, the curves would be straight lines, one vertical and the other horizontal, i.e. at 90°.

(iii) With a system as in practice, there is a substantial angle between the two curves.

(iv) The larger the angle the better the regulation. The regulation being based on feeder load, the regulation shown by the curves derived from feeder load is better than shown by the curves derived from an individual consumer's load.

(v) Clearly, the load curves calculated from the average current for selected voltages are the curves for weighting the voltage distribution curve; the addition of load curves calculated from the average voltage for selected loads is interesting as a picture of the regulation is then obtained.

SOME NOTES ON THE STABILIZING OF HIGH-FREQUENCY POWER AMPLIFIERS.*

By J. Greig, M.Sc.(Eng.), Associate Member.

(*Paper first received* 14*th August, and in final form* 17*th December*, 1934.)

Summary.

The paper reviews in a simple way the principles which apply to the neutralizing of high-frequency amplifiers employing 3-electrode valves.

A critical comparison is made between the practical circuits commonly employed in wireless transmitters and the fundamental circuits.

Introduction.

The output units of practically all, except the smallest, wireless transmitters employ 3-electrode valves in Class B stages. The methods employed for the stabilization of such stages now follow a fairly well-established practice. In describing the principles of these methods, certain elementary considerations in connection with neutrodyne circuits are not infrequently overlooked, and it is the purpose of this paper to consider some of these points.

Fundamental Principles.

In any high-frequency amplifier the grid-anode capacitance of the valve furnishes an unwanted coupling between output and input circuits. This coupling will, in general,

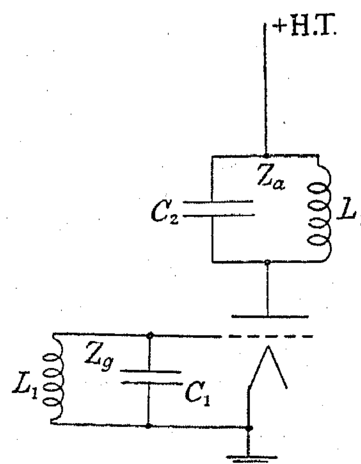

Fig. 1a.

unless means are employed to prevent it, cause any voltage existing across the output to produce a small voltage across the input terminals. Fig. 1a represents a single stage of tuned-grid, tuned-anode amplification.

It will be supposed that the anode and grid circuits are of relatively low resistance and tuned to the same frequency, i.e. $L_1C_1 = L_2C_2$, where C_1 and C_2 include the grid-filament and anode-filament capacitances respectively; also that the grid-anode capacitance, C_{ga}, is small in comparison with either C_1 or C_2. In Fig. 1b the circuit is redrawn showing the valve equivalent generator. Z_a and Z_g are the impedances, between terminals, of the anode and grid circuits respectively, and μ and R_a are the amplification factor and anode differential resistance of the valve. Consider the effect of a small alternating voltage e_g applied to the grid. This will produce an equivalent e.m.f. of μe_g in the anode circuit and an output voltage of approximately $\mu e_g Z_a/(Z_a + R_a)$. If C_{ga} is negligibly small this output voltage will, obviously, have no appreciable effect on the input circuit. In the triode, however, the effect of C_{ga} is never negligible except at very long wavelengths, and in general, if an alternating voltage E_a were applied across the terminals of Z_a, a voltage would appear across the terminals of Z_g. Now in practice the driving grid-voltage may be a modulated high-frequency wave having

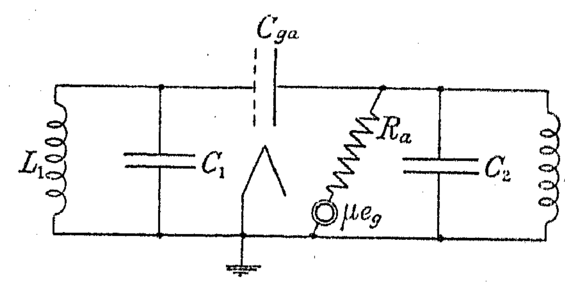

Fig. 1b.

components of frequencies up to 1 or 2 per cent above and below the carrier frequency, so that it is of interest to note how the voltage produced across Z_g by a voltage E_a, applied across Z_a, varies with frequency over a range from a little above to a little below resonance. If the frequency is increased a little above resonance the impedance Z_g passes from an almost pure resistance to an almost pure negative reactance, while if the frequency is depressed a little below resonance an almost pure positive reactance results. Thus, at a frequency very close to resonance the voltage produced across Z_g will be in quadrature with E_a. A little above this frequency, anode and grid voltages will practically correspond in phase, i.e. anode and grid will swing up and down together, while a little below this frequency their voltages will be in almost exact phase opposition and the grid will swing down with respect to the filament as the anode swings up. Now a triode circuit in which an alternating anode potential produces an alternating grid potential 180° out of phase with it, is said to possess positive retroaction, and if, in addition to phase opposition, the voltages possess suitable relative magnitudes at a frequency sufficiently near resonance for either anode or

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grid circuits to have considerable oscillatory energy, a self-sustaining oscillation may be set up.

In order to examine possible modes of self-oscillation of a circuit it is necessary first to determine its natural periods of free oscillation and then to note which, if any, of its natural modes would give suitable relative magnitudes and phases of anode and grid voltage. Consider the circuit of Fig. 1B, omitting the valve equivalent generator; this circuit has two natural frequencies which are readily determined by applying the principle that, in any circuit of low decrement the natural frequencies are almost identical with the frequencies at which the network presents zero reactance to an impressed e.m.f. If, as has been assumed, $L_1C_1 = L_2C_2 = LC$, the two natural frequencies of this circuit are given by

$$\omega_1 = \frac{1}{\sqrt{(LC)}} \quad \text{and} \quad \omega_2 = \frac{1}{\sqrt{\left[LC\left(1 + \frac{C_{ga}}{C_1} + \frac{C_{ga}}{C_2}\right)\right]}}$$

The first mode of oscillation is evidently one in which oscillatory currents circulate round anode and grid circuits and their magnitudes and phases are such that the potential difference across C_{ga} is zero at every instant. The second mode is one in which the circuits L_1C_1 and L_2C_2 both present inductive reactances between terminals.

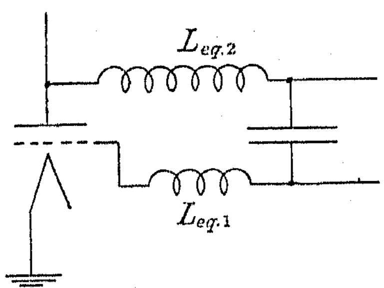


FIG. 1C.

These inductive reactances in series resonate with the capacitance C_{ga}. Evidently, if C_{ga}/C_1 and C_{ga}/C_2 are small in comparison with unity, ω_1 and ω_2 will be displaced only slightly from one another. The first mode of oscillation could never be self-sustaining, as anode and grid would swing up and down together with respect to the filament. Suppose, for the second mode, that the circuit is redrawn with L_1C_1 and L_2C_2 replaced by their equivalent inductive reactances (Fig. 1C). It is immediately obvious that a Hartley circuit has been formed in which the anode and the grid swing in opposite phase; and, if $L_{eq\cdot 1}$ and $L_{eq\cdot 2}$ bear a suitable relation to one another, sustained oscillations will be produced. Thus the presence of C_{ga} renders it possible for a circuit to oscillate or tend to oscillate at frequencies at which the anode and grid circuits have a positive reactance. If the values of $L_{eq\cdot 1}$ and $L_{eq\cdot 2}$ are suitable for the production of sustained oscillations and C_{ga} is relatively small, as would be the case except at very short wavelengths, relatively large currents will circulate in the two oscillatory circuits while a small " feed " current flows back and forth through C_{ga}. In practice, of course, the presence of effective resistance upsets the phase relations to some extent.

This phenomenon of retroaction through the grid-anode capacitance is ordinarily minimized in low-power stages by the use of screen-grid valves, but in high-power stages triodes are used and stabilized by neutro-

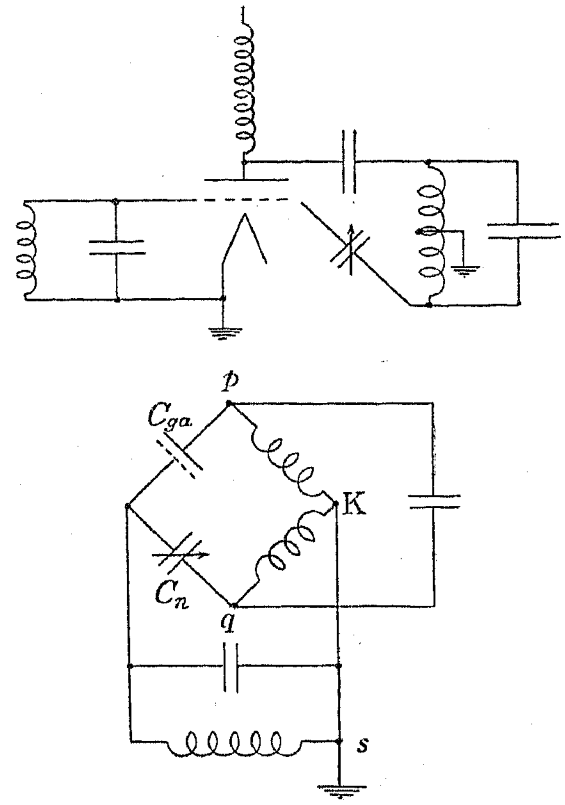


FIG. 2.

dyning, i.e. by modifying the circuit arrangement so as to place the valve in a form of impedance bridge, so balanced that the output voltage can produce no appreciable voltage across the input circuit by means of the coupling furnished by C_{ga}.

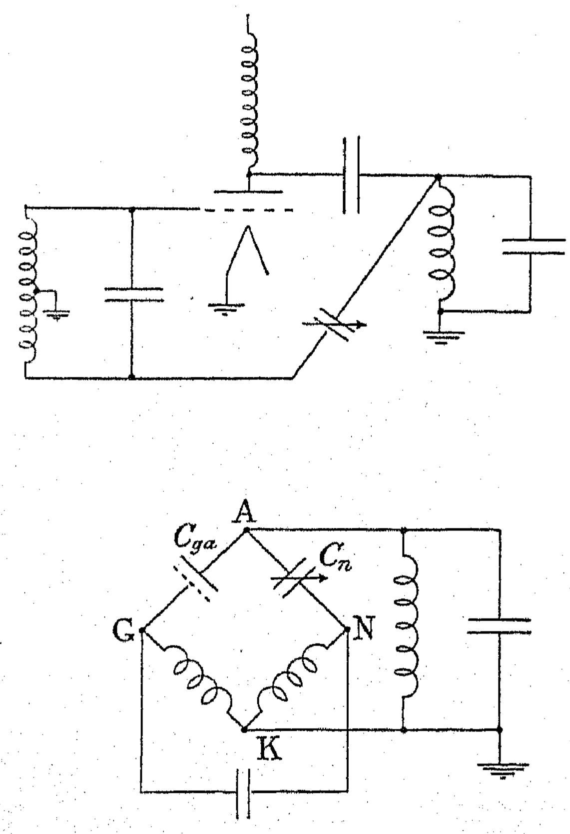


FIG. 3.

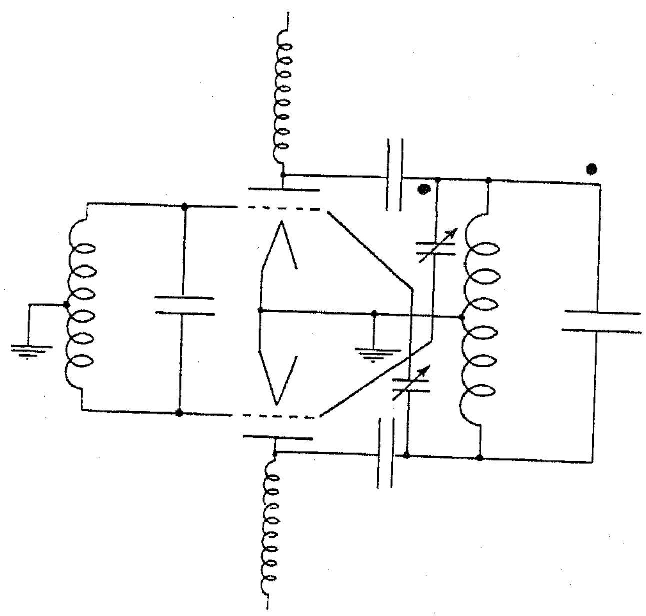
It is evident from the foregoing considerations that, if we drive an unneutralized circuit, the retroaction may be positive or negative depending upon the frequency, and

even if the coupling is insufficient to produce self-oscillation the amount of amplification obtained with a drive of given strength may vary enormously over the frequency band being transmitted. Thus any neutrodyne arrangement must maintain a balance, at least over the whole frequency range required to be transmitted, quite apart from inhibiting self-oscillations at frequencies lying outside that range.

The two fundamental neutrodyne circuits were suggested by Rice and Hazeltine. Both depend on auto-transformer properties, but one may be said to " split " the anode circuit while the other " splits " the grid circuit. It is important to realize that the requirement for a truly neutrodyned circuit is, not that a voltage existing *across* the output circuit should produce no voltage *across* the input circuit, but that any a.c. voltage existing between anode and filament should produce no voltage between grid and filament.

Hazeltine's circuit is shown in Fig. 2. Suppose, for convenience, that K is a centre tap on the anode coil and that $C_n = C_{ga}$. It is evident that any a.c. voltage applied across the output circuit, i.e. across pq, would, neglecting resistance, produce no voltage across rs, the input circuit. The valve equivalent generator acts not between p and q, however, but between p and K. Thus e_g will only be unaffected by μe_g at all frequencies if pq acts as an auto-transformer with no magnetic leakage. In spite of the fact that the coil pq always has considerable magnetic leakage and that the balance is upset by the effective resistance of the circuits, fairly satisfactory balances can be obtained by this means at the longer wavelengths.

Rice's circuit is shown in Fig. 3. Suppose, as before, that $C_n = C_{ga}$ and that K is a centre tap on the grid coil GN. As in the previous case, a voltage applied across the output KA would produce no voltage across the input GN, but, unless GN is a centre-tapped coil with no magnetic leakage and negligible resistance, the valve equivalent generator acting between A and K will produce a voltage between grid and earth. (From the symmetry of the circuit, G and N are always equipotential points and can thus be imagined commoned. Then between GN and K, there are two coils of equal inductance, negligible resistance, and unity magnetic coupling, connected magnetically in opposition, the impedance of the combination being therefore zero.) Again, circuits can in practice be stabilized despite the presence of resistance and magnetic leakage. When push-pull circuits are used instead of single-valve circuits the Rice and Hazeltine circuits automatically combine (Fig. 4). Where perfect auto-transformer action exists and resistance is negligible it is evident that the equivalent generator of either valve independently, or of both acting together, will produce no voltage between grid and earth.



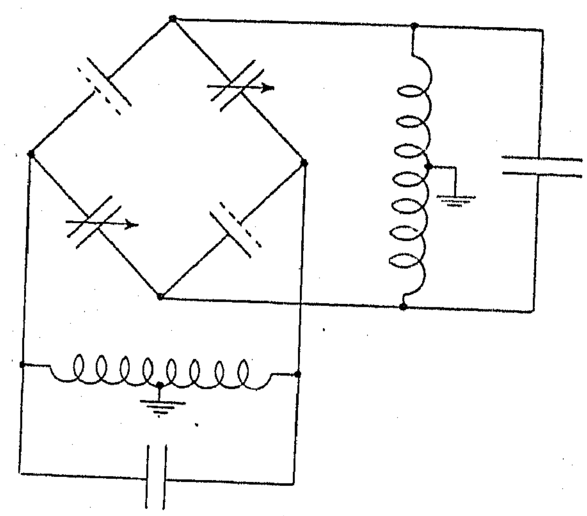


Fig. 4.

Practical Circuits.

In practice neither the Rice nor the Hazeltine circuit is used in its original form. For one thing, it is obviously difficult, if not impossible, to design a high-voltage, high-frequency inductance with small magnetic leakage; and, more importantly, the practice of using inductances with tappings connected to earth leads to great difficulties with parasitic oscillations, for which the oscillatory circuits are formed, generally, by the valve capacitances and the inductances of the leads, and not at all by the input and output circuits. This is especially true of the grid circuit. It is often necessary in practice to increase the grid-filament capacitance of the valve artificially by external condensers in order to reduce the tendency of transmitting valves to oscillate on parasitic wavelengths. The neutrodyne circuits generally used take the form of capacitance bridges and employ no mutual inductance. This facilitates the use of anti-parasitic grid-filament condensers, and in addition the bridge can frequently be arranged so that the effective resistance of the oscillatory circuits is not introduced into it. The circuit most commonly employed for long- or medium-wavelength circuit stabilization is shown in Fig. 5. The grid circuit is split symmetrically, as in Rice's arrangement, but on the capacitance instead of on the inductance limb. Suppose the bridge is balanced as before by mak-

ing $C_n = C_{ga}$. Then the presence of μe_g will produce no voltage across the input circuit at any frequency, but will produce a voltage between grid and earth. Obviously, however, grid and anode will swing up and down together,

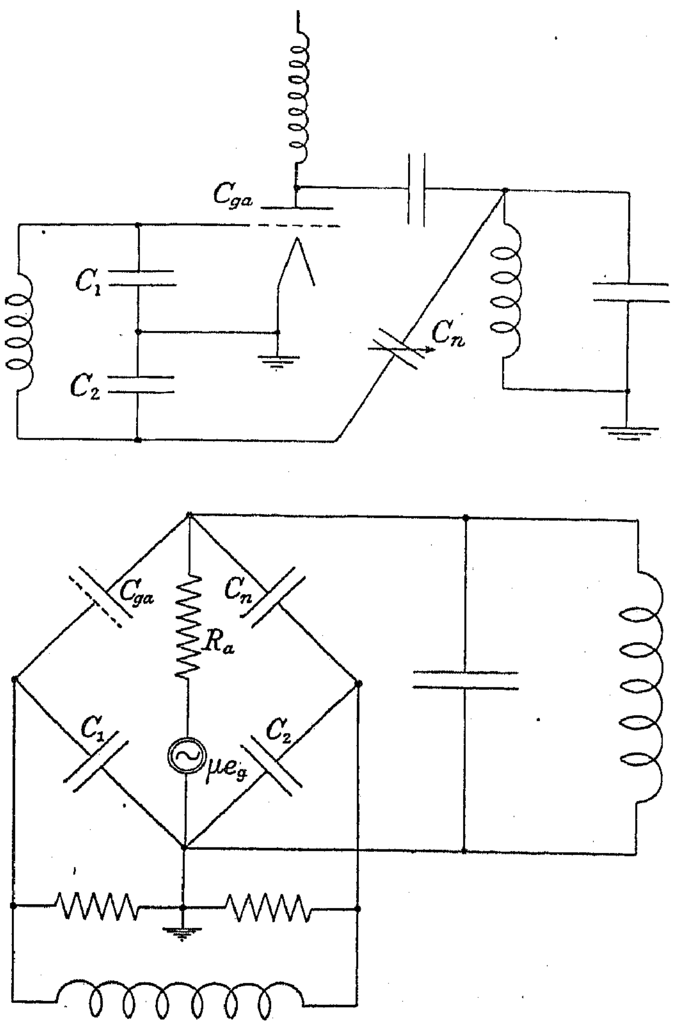


FIG. 5.

i.e. only negative retroaction will be present, and its magnitude, which will be independent of frequency, can be made almost as small as desired by making C_1 and C_2 large in comparison with C_{ga}. The anode circuit is loosely coupled either to the aerial circuit or to the input circuit of the next stage, and this coupling throws back a small effective resistance into it. A centre-tapped shunt resistance is placed across the input circuit, partly to minimize residual retroaction and any tendency to parasitics and partly to render the circuit sufficiently flat to make side-band cut-off negligible over the required frequency range.

Consider now the effect of making corresponding modifications in Hazeltine's circuit (Figs. 6A and 6B). As before, a voltage applied across the output circuit will produce no voltage across the input. μe_g, however, acts between anode and earth and it is evident that, if the capacitance bridge is balanced for voltages applied across its diagonals, it can only be balanced at the resonant frequency for voltages applied across A and K, and such a balance will only be approximate on account of the effective resistance of the anode circuit. Suppose that the capacitances C_1 and C_2 are large in comparison with the valve capacitance, so that the potential distribution across A, K, and N, is determined almost wholly by the circuit C_1, C_2, and L_1. Then, for the resonant frequency of the anode circuit and for frequencies slightly above and slightly below resonance, three approximate vector diagrams can be drawn for a given voltage produced across AN by μe_g (Fig. 6c). The point G will tend to remain midway in potential between A and N. At resonance K will be at approximately the same potential, while for frequencies slightly below resonance it will fall above G as at K_1, and for frequencies slightly above resonance as at K_2. Thus for frequencies slightly below the fundamental, positive retroaction will be present, and for frequencies slightly above, negative retroaction will exist. Such a circuit, with a valve of high μ/R_a and circuits of relatively low decrement, simply oscillates as a Colpitts oscillator at a frequency slightly below resonance; and even if the circuit does not self-oscillate the amplification will obviously vary widely with frequency.

Practically, however, the push-pull circuit offers great advantages from the point of view of minimizing both radio-frequency harmonics and the departure from linear response under modulation. It is also less subject to parasitics, especially at the shorter wavelengths. The majority of transmitter output stages are consequently of the push-pull type. Here again, centre-tapped condensers and not centre-tapped coils are used, for the same reasons as in non push-pull circuits. The circuit (Fig. 7) is made physically as symmetrical as possible with respect to earth; and valves with as nearly as

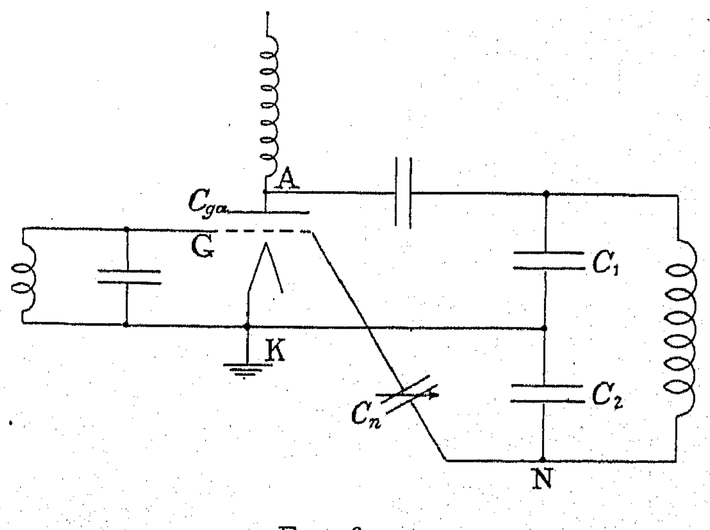


FIG. 6A.

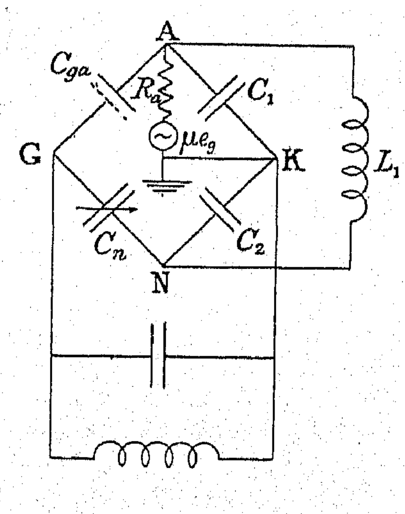


FIG. 6B.

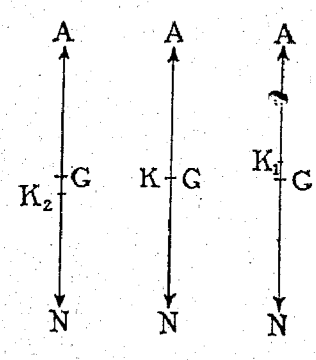


FIG. 6C.

possible identical characteristics are employed. To a high degree of approximation, therefore, any voltage applied symmetrically across the input produces an amplified symmetrical voltage across the output, and a voltage of any frequency existing symmetrically across the output will produce no voltage between either of the grids and earth. In regard to self-oscillations at frequencies near the fundamental, the behaviour of the unneutrodyned circuit is similar to that of the single-valve circuit in that it has a second mode of oscillation at such a frequency that anode and grid circuits act as inductive reactances which resonate with the two valve capacitances in series. This is the familiar Hartley short-wave push-pull circuit (Fig. 8). Now any tendency to such self-oscillation can evidently be minimized by cross-neutrodyning, provided the oscillation tends to take place symmetrically with respect to earth, as it ordinarily does. Thus the balance of the circuit depends upon the two R_a values being equal and the two μe_g values being equal and in phase opposition. It appears, then, that in the case of a push-pull circuit driven with only one filament alight or having two valves of very different characteristics, either positive or negative retroaction will be present depending upon whether the drive frequency is above or below the fundamental.

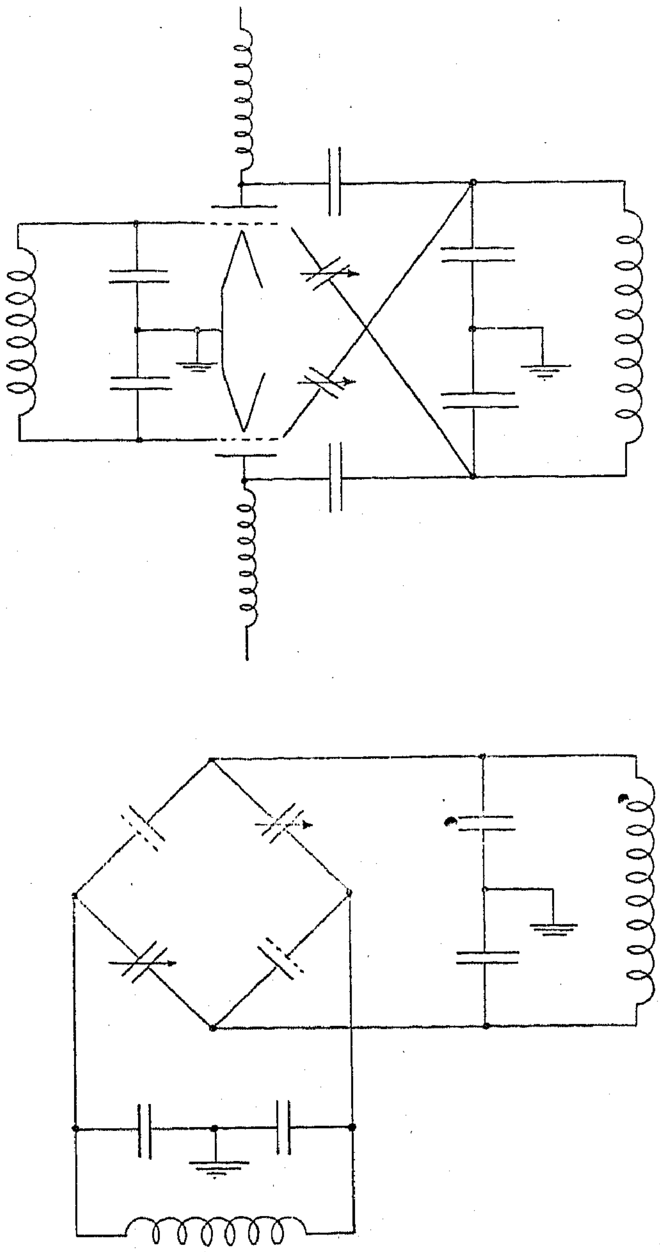


FIG. 7.

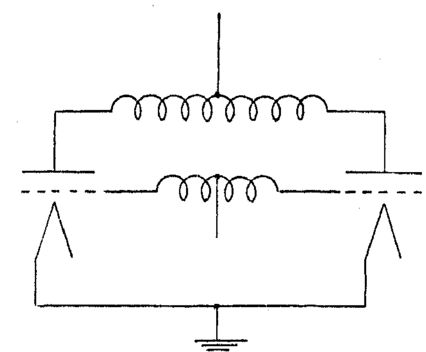


FIG. 8.

Strictly speaking, the use of the valve equivalent generator implies " linear " valve operating conditions and is not therefore legitimate with Class B amplifiers. Obviously, however, it can be used to investigate conditions of incipient instability in such amplifiers, and in practice it is found that the performance of Class B stages follows qualitatively what would be predicted from " linear " theory.

DISCUSSION ON

"COPPER LOSSES IN LARGE CABLES AT POWER FREQUENCIES."*

Mr. H. Waddicor (*communicated*): The critical comparison in this paper between various more or less approximate skin-effect formulæ places all electrical engineers and students under a debt of gratitude to the author, as, hitherto, there has been little or no clue to the best practical methods of calculation in any given case. This confusion has been due not only to the multiplicity of apparently contradictory curves and formulæ in existence, but also to the loose or misleading statements made by various writers on the subject. Sources of information in my own possession, for example, give all sorts of figures, ranging from 8 per cent to 20 per cent for the skin effect in a 1 sq. in. copper conductor at 50 cycles per sec.

Whilst the problem of skin effect in stranded conductors has now been solved, however, it seems unlikely that the same certainty of knowledge will be reached as regards proximity effect. This is unfortunate, as with many practical types and sizes of cable proximity effect may be the chief source of loss due to unequal current density. This uncertainty is introduced by the variable character of the contact resistance between the adjacent individual wires and layers of wires forming the conductor, the extreme cases being those of infinite and zero contact resistance. With infinite contact resistance the current in the conductor follows a spiral path corresponding to the lay of the individual wires, thus entirely eliminating all proximity effect. On the other hand, with zero contact resistance the current flow is purely axial, the proximity losses having their maximum value corresponding to a solid conductor of the same total cross-section and resistance as the stranded conductor.

Opinion has hitherto been undecided as to which of these assumptions is correct, but the present investigation, although of limited scope, seems to show that the proximity effect is about one-half of that in the equivalent solid conductor, so that the actual current-flow is neither wholly spiral nor wholly axial. Nevertheless, there are so many factors influencing the contact resistance that different samples of conductors may exhibit very wide variations in the proximity-loss ratio. In this connection the following recent statements from American sources are of interest:—

(1) "One of the baffling problems in cable inspection has been the marked discrepancy encountered at times between the measured resistance of a conductor and its area. As these cases usually occur in connection with short-lay, sector conductors, it had been suggested that variation in contact resistance between the strands might be the explanation. Careful investigation was, therefore, made by one of the organizations represented on this committee and it was found that the strands are always effectively insulated from each other and that the discrepancies in question are entirely due to errors in one or more of the various measurements."†

(2) "The usual method of stranding is to lay alternate layers of strands in opposite directions. When the strands are tightly and compactly applied in this way but not rolled or crushed it leads to relatively high proximity loss, because the circulating current is concentrated at those points of contact where the strands cross. Rolling or crushing the contactor will increase the area of strand contact and reduce the concentration of current. The more compactly the strands are crushed, particularly the outer layers, the greater will be the reduction in proximity loss."‡

It is difficult to reconcile these two extracts, and the claim that a reduction in loss is secured by improving the contacts between individual wires is so opposed to what might be expected, as to be unacceptable in the absence of experimental proof. Evidently much still remains to be cleared up, and any further investigation should be devoted to finding out the magnitude of the phenomenon when the stranded conductor forms part of a complete cable and is heated to maximum operating temperature by means of load current. It seems almost certain that under these conditions the combined effect of conductor expansion and increased hydrostatic pressure would almost eliminate any contact resistance. Hence it would be inadvisable, in my opinion, to assume anything less than maximum (solid-rod) proximity loss as a basis of current loadings.

Proximity losses are most serious with multicore cables, where the ratio between conductor diameter and interaxial spacing is comparatively large. Under these conditions, losses due to this source are greater than those due to skin effect and, where large sections of conductor are concerned, may substantially modify the current-carrying capacity of the cable. A low-tension 3-core 1-sq. in. cable, for example, would probably have a proximity loss of the order of 30 per cent. Sheath and armour losses would also be heavy, but allowing only for the elimination of proximity losses the current rating, doubtless, could be increased by about 10 per cent. Complete elimination would be secured by covering the individual wires with enamel or other insulating media, but special designs of conductor are also in use which, although built up with uninsulated wires, result in an extremely low proximity loss. One of these special sections is produced by stranding successive layers of wires in the same direction, and this type of conductor is referred to here because the investigation of its proximity loss has thrown a new flood of light on the nature of current-flow in the normal type of conductor

* E.R.A. Report (see page 299).

† "Acceptance Inspection and Testing of Cable" (Underground Systems Committee Report No. 162), *Proceedings of the National Electric Light Association*, 1932, vol. 89, p. 1093.

‡ E. H. Salter, G. B. Shanklin, and R. J. Wiseman: "Resistance and Reactance of 3-Conductor Cables," *Electrical Engineering*, 1934, vol. 53, p. 1581.

where successive layers of wires are stranded in opposite directions.*

What appears to take place in a normal stranded conductor is that the current flows along the following three paths:—

(*a*) Spirally along the individual wires,
(*b*) Axially from wire to wire in the same layer,
(*c*) Axially, but in a more or less zigzag direction following first along a wire in one layer, then along one in the next layer, then again along a wire in the first layer, etc.

That part of the current following the spiral path (*a*) is not affected by the proximity of the return current, but both currents (*b*) and (*c*) give rise to proximity loss. Now, since the path for current (*c*) includes far fewer contacts per unit length of cable than the path for current (*b*), it may be expected that by far the greater part of the current flowing axially utilizes the former path.

By stranding all the wires in the *same* direction, the zigzag path followed by the bulk of the current is suppressed, and the only axial path available is that from wire to wire in the same layer; hence, the substantial reduction in proximity losses found with this conductor, which, notwithstanding disadvantages from a mechanical point of view, is apparently being used for practical cables.

Dr. A. H. M. Arnold (*in reply*): Mr. Waddicor's remarks on proximity effect are valuable, but I cannot agree that if the contact resistance between strands were eliminated the proximity loss would be the same as in a solid rod. The path for the proximity eddy currents would still have a higher resistance than in a solid rod, as the current would flow along a path of varying section and only at the points of maximum section would the section be approximately equal to that of the solid rod. I think it is possible that at high frequencies the proximity loss in the stranded conductor might even be higher than in an equivalent solid rod.

I agree with Mr. Waddicor that the proximity effect in a complete cable operating at its full temperature-rise would almost certainly be greater than that observed in the uncovered cores tested in connection with Ref. F/T55. Unpublished test results show in one case that the proximity effect reaches 84 per cent of the calculated value for an equivalent solid rod. The uncertainty in the calculation of the proximity effect is not, however, a serious matter in the case of single-conductor cables at power frequencies. For example, the resistance of a $1\frac{1}{2}$ sq. in. low-voltage cable laid in close proximity to its return conductor and with sheaths bonded would be about twice as great with alternating current, at a frequency of 50 cycles per sec., as it would be with direct current. The proximity loss in the core in this case is only about 7 per cent of the total loss in the cable.

The problem may be more serious for large 3-core cables, since the cores are very close together, thus increasing the proximity effect while the sheath losses are relatively much smaller. If these cables are used to any extent it would be extremely valuable to have experimental information as to the value of the proximity effect for cables of normal construction and cables of the special designs described by Mr. Waddicor.

* L. MEYERHOFF: Discussion on "Resistance and Reactance of 3-Conductor Cables," *Electrical Engineering*, 1935, vol. 54, p. 325.

DISCUSSION ON
"HYDRO-ELECTRIC DEVELOPMENT IN GREAT BRITAIN, WITH SPECIAL REFERENCE TO THE WORKS OF THE GRAMPIAN ELECTRICITY SUPPLY CO."*

North-Western Centre, at Manchester, 18th December, 1934.

Mr. P. W. Seewer: The author has told us of the antagonism there was to hydraulic plant some 10 or 15 years ago; I can corroborate this statement by saying that not very many years ago, when I tried to awaken interest in this same subject of British hydro-electric engineering, the response was very mild indeed. No doubt opinion at that time was greatly influenced by the totally wrong idea that hydro-electric machinery could not be built in this country but would have to come from abroad. The paper gives us an excellent opportunity of judging for ourselves what can be done in this country, as the largest part of the machinery described by the authors is entirely British, in both design and manufacture. The British manufacturing firm with which I am associated has installed hydro-electric machinery of upwards of 750 000 h.p. all over the world. More than 300 000 h.p. of this we have installed in Scotland alone.

British manufacturers, immediately after the War, took the initiative in creating the necessary organization, as well as the necessary facilities, for research to enable them to develop hydro-electric machinery which would operate satisfactorily.

I should like to mention that, according to the findings of the Water Power Resources Committee, there are between 65 and 70 million h.p. of potential water power in the British Empire alone, a large part of which is capable of being harnessed under sound economic conditions. It would be of considerable help to our home industries if a reasonable share of the enormous water-power resources all over the world, in Great Britain and the British Empire in particular, could be developed in this country.

Mr. G. F. Sills: A short time before the Bonnington station was commenced I inspected the stretch of the river involved, and a remark was made that it would be quite impossible to allow anybody to interfere with the scenic beauty. The project has been carried out, however, and I have been informed since that there is not much amiss, in spite of the fears that were expressed at the time.

It is not common knowledge that as long ago as 1927 an English manufacturer made five 30 000-h.p. sets for one hydro-electric power station in India.

In my Chairman's Address† two years ago, I mentioned that before very long Lancashire would be receiving power from Scotland. The present paper makes it quite clear where this power is coming from. We have to remember that in the event of a railway crisis, or a coal strike, the country would be exceedingly thankful for this avenue of power.

Are any precautions taken against ice at the intake of the hydro-electric plants in the North of Scotland?

On a visit to Quebec, Canada, I noticed that many thousands of horse-power were sold by the power company in the form of energy delivered through turbines at the shaft of a paper mill.

I believe that at the Lochaber power house a current of no less than 80 000 amperes is maintained on the busbars continuously for months on end. The turbines for the Kinlochleven scheme were originally made many years ago; they have since been reconstructed by an English manufacturer, and their efficiency has been considerably increased. Table 4 shows that, out of the hundreds of thousands of horse-power developed by hydro-electric stations in Great Britain, only 17 000 h.p. is municipally owned.

With reference to the Severn scheme, at the time this was broached the question of capital cost was much to the fore, but since then events have shown that this need not stand in the way.

Mr. W. Fennell: About 1900 I had to do with a proposed scheme for the electric lighting of Seaford and Newhaven, in Sussex. On visiting the place I found a tidal water-power scheme, not running, but so old that it had fallen into disuse and was derelict. We seriously thought of using it. It consisted of two pools called "salts" on the seashore, I should think about ½ mile to the east of Newhaven Harbour, and there were sluices and a water wheel. It was clear that one of the "salts" or pools was filled at high tide and that the gates of the other were closed at low tide, the water being run through from the high salt to the low salt when power was required for the corn mill. Judging by its appearance the plant had worked up to about 1880 or 1890.

Mr. R. M. Charley (*communicated*): It is very interesting to note that the engineers responsible for the Grampians scheme decided to use separate regulating transformers at Rannoch, whereas on the transformers installed at Abernethy on-load tap-changing gear is provided on the main units, and there are no separate regulating transformers. This is somewhat surprising in view of the fact that the former transformers are quite simple units, used only for stepping up the generator voltage to the transmission voltage of 132 kV, whereas the transformers at Abernethy are rather special 3-winding units.

From the purely engineering point of view a separate regulating transformer is preferable, but the cost is

* Paper by Messrs. A. S. Valentine and E. M. Bergstrom (see page 125).
† *Journal I.E.E.*, 1933, vol. 72, p. 45.

greater, and hence the alternative arrangement of on-load tap-changing on the main transformers has been very widely adopted. Experience of this arrangement on the grid, where about 12 million kVA of such transformers are employed, has been quite satisfactory. The question that naturally arises in connection with this problem is the range of voltage variation that can be given with on-load tap-changing equipment. The transformers on the grid have a range of 20 per cent, but this is by no means the limit; if a 30 per cent range were demanded, designers would be quite prepared to offer it. The factors that have to be seriously considered in this problem are variation of impedance and mechanical stresses under short-circuit, but both of these difficulties can now be solved by judicious design.

I should like to ask the authors to explain why it was considered necessary to insulate the neutral of the 132-kV line to Abernethy, whereas the grid system is solidly earthed.

Recently I had the privilege of visiting the power plants at Niagara Falls; in one station it was wonderful to see nearly 500 000 h.p. of plant running at a load factor of about 99 per cent. I learned that every month the runners of the turbines are touched up, by welding, to minimize the effects of erosion. In this country I understand that this is not necessary because the runners are better designed and suitable precautions are taken to prevent erosion.

The question of amenities has been raised several times in the discussion: it is interesting to know that there is little risk of hydro-electric work at Niagara Falls destroying the grandeur of the Falls. The authorities are, however, concerned about the rapidity with which the crest of the Horseshoe Falls is being broken away. If this is not remedied the spectacle will be largely destroyed, and a Commission is therefore engaged in preparing plans for the carrying-out of the necessary work.

Mr. H. Headland (*communicated*): Referring first of all to the Loch Ericht scheme, I should like to know whether the concrete-lined pressure tunnel was tested section by section before the station was put into operation. Particulars of the methods adopted would be useful. There have been one or two cases of the pressure lining failing from lack of these precautions. The loss of head and coefficient of friction for tunnels lined with concrete are quantities of doubtful magnitude, and it would be of considerable value if some experiments were carried out in this direction. Could the authors say whether measurements of these quantities have been made on the Loch Ericht tunnel, and, if so, whether any definite conclusions have been reached?

In connection with the pipe-line, can the authors indicate the constitution of the rust-preventing solution and the method by which it was applied?

The use of bronze alloys for turbine runners was borrowed from the marine engineer, but experience has proved that bronze-alloy propellers have not been immune from cavitation difficulties. On the hydraulic side, opinion is more or less divided, and I should like to know whether cavitation effects have been observed in the case of the Grampian scheme. Also, has any difficulty been experienced during operation, owing to governor oils frothing?

In the course of the efficiency tests on the turbines were comparative results obtained by the salt velocity, Pitot tube, and velocity meter, methods? In France a method of efficiency measurement on load by determination of the temperatures of the head and tail waters has been advocated. I should be glad if the authors would indicate whether this procedure has practical applications, and also state its limitations and degree of accuracy.

It would appear that there would have been some economy of excavation if the surge tanks had been made of the inverted-cone type, although probably the characteristics of the turbines and pipe-line determined the shape adopted.

With reference to the Loch Rannoch scheme, could the authors in their reply give an outline drawing of the siphons installed, together with some idea of their capacity and the arrangements made for automatic priming?

In some cases fish-shaped sections have been recommended for use on screens, to eliminate loss of head. Have the members of the screens been made of any particular shape in this instance, and has stainless steel been used in their construction?

I am particularly interested to learn that a built-up welded pipe-line has been constructed in this country. It would have added considerable value to the paper if the authors had indicated the nature of the routine tests and special tests carried out to prove the welding during construction. In important structures it is now almost standard practice to take X-ray photographs of all welding immediately after it has been done, and I should like to know whether this was done on the Loch Rannoch scheme. If so, could the authors give some typical illustrations of good and bad welding revealed by this method?

With regard to the lay-out of the Loch Rannoch station, it would appear that outdoor transformers could have been used to advantage. The specific speed of the turbines would seem to indicate that vertical units would have been an economical and sound proposition, in addition to reducing the number of runners and eliminating the branches in the pipe-line at the turbine inlet. Were there any special reasons for adopting indoor transformers and double-runner turbines? Could the authors state the chromium content of the stainless-steel runner blades? This factor has an important bearing on suitability for turbine work. Finally, were the runner blades heat-treated, and has cavitation taken place?

[The authors' reply to this discussion will be found on page 712.]

North Midland Centre, at Leeds, 5th February, 1935.

Mr. C. S. T. Paul: That the development of water power in the British Isles is economical is clearly indicated by the fact that during the past 7 years the installed capacity of hydro-electric plant has increased from

80 000 kW to over 250 000 kW, the latter representing approximately 50 per cent of the total power development which has been surveyed as economical.

It is interesting, however, to determine the limit to the capital cost of a scheme in order that it may effectively compete with electricity produced from thermal stations. Just as in the case of a thermal station, so also is it in the case of hydro-electric installations, that the cost per unit depends upon the load factor. To the cost of generation must be added the cost of transmission. Let us take for an example the Galloway scheme. It was originally intended to operate with a load factor of 21 per cent, at which it was estimated that energy could be generated at about 0·34d. per unit. The surrounding district is at present unable to absorb 100 000 kW, so that the bulk of the energy must be transmitted some 50 miles or more, thus increasing the delivered cost of the energy to about 0·36d. per unit. This is somewhat more than the cost of energy which may be produced for the grid by most large thermal stations. To allow of this scheme to compare favourably with the energy available from the grid, it is necessary to operate at a higher load factor, say 35 to 40 per cent, and at such load factors the capital cost of the scheme must not exceed £25 to £28 per kW capacity installed. Whilst the development of our water-power resources is, in my opinion, a step in the right direction, the example just given does tend to show how necessary it is to provide a high load factor. With the exception of the Grampian and Galloway schemes, the water power so far developed has been mostly in connection with the aluminium industry. It would be interesting to know the load factor at which the stations of the Grampian Supply Co. operate, and also the approximate capital cost per kW installed.

Perhaps the greatest development which has taken place in water-power engineering during the last 20 years has been that of the high specific-speed or propeller type of water turbine and draught tube. This furnishes a means of increasing the speed of the turbine and generator for the same output, and thereby enables the overall dimensions, weight, and space required, all to be reduced. It is particularly suitable for low and medium falls and therefore would appear to have a wide scope in this country, where the general elevation of the country is relatively low. In this connection it is of interest that there are no such turbines in excess of 500 h.p. installed in this country. This type of turbine would no doubt be adopted for pump-storage and tidal schemes, if such were ever developed.

I should like to know whether any special brand of cement was used in the concrete for the aqueduct, as I understand that ordinary Portland cement is liable to become pitted under the action of moorland and peaty water.

It is interesting to note that the steelwork used in the substation structures is encased in concrete. As a protective covering this would appear to be an uneconomical method, and such a process as "parkerizing" or good-quality paint would appear to be satisfactory and much cheaper. It would at the same time facilitate extensions and alterations. Such white-concrete structures erected in moorland country are, in my opinion, far more unsightly than the thinner-sectioned and darker-coloured steel structures.

I note that stand-by protection operating on the negative phase-sequence principle is installed, and I should be glad if the authors could say whether this system of protection has operated under heavy faults external to the circuit which it is protecting.

Mr. R. M. Longman: It is gratifying to know that the installations referred to in this paper are approximately 99 per cent British, and to find that British manufacturers are in a position to tackle jobs of this nature in all parts of the world.

I favour the use of reinforced-concrete structures which, particularly in the uncontaminated atmosphere prevailing, are attractive in appearance. I should like to know whether any deterioration of the concrete has been experienced owing to this having been mixed with peaty water, or whether precautions were taken to avoid the use of such water.

With reference to the use of galvanized-steel towers, the galvanizing should have an extremely long life in the greater part of the area of the Grampian Supply Co. I am interested to note the use of towers carrying four circuits at two different voltages. Has trouble been experienced on any one circuit owing to induced effects from a fault on one of the other circuits?

Rather extensive use has been made of star/star-connected transformers having tertiary windings. This is of advantage when it may be necessary to earth the neutral points of the two principal systems, and the provision of tertiary windings having a thermal rating 36 per cent of that of the main windings should prevent any possibility of damage to these windings under fault conditions. It is, however, just as necessary to anchor, reinforce, and support, the tertiary windings as the main windings. The use of the tertiary windings for metering by means of phase compensation is of interest. In this area of the grid system, 132-kV potential transformers are provided and have proved most satisfactory.

On the question of the line insulators, I should be glad to know how long these have been in commission and whether many failures or signs of deterioration or puncturing have been noted, and, further, whether any method is adopted for testing the voltage gradient on the strings of insulators whilst in commission.

The use of graded arc-gaps when approaching substations as a protection against surges and lightning is of interest, and further information as to the amount of grading and the method of application is awaited.

On page 149 the use of 33-kV lines for a distance of approximately 60 miles is indicated. Excepting for comparatively small loads, this distance is too great for the voltage; has provision been made for increasing the voltage to, say, 66 kV at a later date, should this be required?

The use of the wired-wireless system for communication and indication purposes is of special interest, and it is to be hoped that as the result of the experience gained thereby we shall be able, with the consent of the Postmaster-General, to make more extensive use of this method of communication.

Mr. P. G. Hieatt: Have the 132-kV air-break isolators given any trouble during the charging-up of the line?

I am rather sorry the paper does not give any comparative figures between the running cost of a water-power station and that of a steam station. I should like to have some information in this connection.

There is also another point. If when an alternator of 20 000 kW was carrying full load that load was thrown off suddenly, would there be any likelihood of trouble on the pipe-line, or would the shock be fully taken care of by the surge tank?

Mr. W. Chambers: As a youth I was taught that the Pelton wheel was the most efficient type of water motor. I should like to know what are the advantages of the Pelton wheel for the Grampian scheme. Also, what materials are used for the manufacture of the turbine blades, and have hydraulic engineers the same trouble as steam engineers due to pitting or corrosion of these blades?

Mr. P. W. Seewer: The installation and manufacture of hydro-electric plant is of great interest in this country from the point of view of national economy; not because it is in any way meant, or even able, to supplant the thermic power production, but because it can contribute by the production of cheap power to utilizing an important national asset to the best possible advantage for our industries. Between experts there is hardly any controversy concerning the question in which cases water power must be given preference over steam power. There is a distinct limit fixed by the price at which the unit can be produced by either water or steam power, and each particular scheme must be judged on its economic usefulness. The position of hydro-electric schemes depends upon the natural conditions of sufficient precipitation and natural accumulation, as well as an adequate difference in level to produce the necessary head. Such schemes are mostly distant from large, populated centres, and the difficulties and costs of transmission lines and distribution must be reckoned with. The question at what price the unit can be produced is, and must remain, the predominating factor.

In the construction of the Galloway scheme, which is touched on in the paper, 3 000 men were employed for several years, apart from the men employed in the manufacture of the machinery. This fact, in lean years like these, should be sufficient to stop the usual rivalry between the defenders of hydro-electricity and the defenders of thermic power.

On the Continent, and in Canada and the United States, many of the important chemical industries depend upon the low price for which hydro-electric power can be produced. The aluminium industry, and many other industries likewise, could not do without this cheap power.

The Authors' Reply to the Discussions at London, Glasgow, Birmingham, Newcastle, Liverpool, Manchester, and Leeds.

Messrs. A. S. Valentine and **E. M. Bergstrom** (*in reply*): We are gratified that, in spite of the inherent difficulties from the point of view of discussion attached to a paper covering such a wide field, the discussions have proved most useful and interesting. To avoid repetition, we propose to group our replies to the various speakers according to the subject matter of their remarks.

It was, of course, inevitable that the question of the cost of hydro-electric works should form a subject for discussion, but we purposely avoided referring to this question in the paper. Our reason for this was that such data are usually misleading for comparative purposes, as in hydro-electric works where the bulk of the expenditure is represented by the civil engineering construction it is essential to distinguish between all the factors bearing upon the development. A figure of cost per kilowatt installed of hydro-electric works constructed for different load factors, or having reference to a storage scheme as compared with a development utilizing the minimum flow only, or without comparing the installed capacity with the ultimate capacity for which the permanent works have been constructed, would give an entirely erroneous idea of the economic values of hydro-electric utilization. Hydro-electric works must therefore be judged on their individual merits, and if comparisons are attempted all the factors have to be reduced to a common basis, e.g. the capital expenditure per kilowatt-hour per annum of primary power. As far as the Grampian scheme is concerned it is impossible at this stage to give any figures of cost, as the full development has not yet been completed and the works comprising it now under construction will require another 3–4 years to finish.

It was suggested in one of the discussions that the adoption of hydro-electric schemes had a psychological aspect, and that the large capital expenditure and the very permanency of the civil engineering construction was the principal drawback to hydro-electric developments. We do not subscribe to these views, as capital can only be attracted to an economical proposition, and any water-power scheme to be proved successful must comply with this factor. In connection with this subject it is, of course, to be remembered that the basis of all economics is the sum total of effort values. In the steam station the running cost is represented by the effort value of winning the coal and the remuneration of capital expended in the coal mines. The amount thus represented is a variable quantity as it is susceptible to the vagaries of economic conditions and in time of crisis may impose a heavy burden on the industry. In hydro-electric plants, on the other hand, as soon as the capital expenditure has been ascertained the yearly charges are practically constant. The charges for depreciation and obsolescence favour the hydro-electric plant; the latter need not be seriously considered, however, as, while the hydro-electric works are "permanent" within the meaning of that word, movable plant can be reconstructed and modernized with comparatively little expense. Apart from these considerations the question of conservation of fuel resources is coming more and more into the forefront as a national policy, and in this connection our remaining water-power resources have a definite and distinct value.

Objections have been raised against the use of the expression "on the same site" (page 130) in connection with the competitive possibilities of water power. The context makes it clear, however, that the expression used

is synonymous with "the point where power is required." This point is generally fixed geographically by other considerations than that of power supply, and hence the expression is intended to refer to the actual site at which power is utilized. In certain industries, of course, such as those employing electrometallurgical processes, the point of demand is generally governed by the availability of cheap power, in addition to considerations regarding transport of raw material, the question of local labour, etc., and in that case different sites have to be compared as regards power costs.

Particularly in connection with the Galloway scheme, the question of the load factor for which hydro-electric schemes should be constructed has been raised. It is, of course, impossible within the limits of this discussion to go into a detailed review of a question which is determined by so many varying factors, such as available storage, capital expenditure, and the conditions relating to the demand for power. As a general rule, however, hydro-electric works are most suitable for supplying base loads, although in certain specific circumstances, when a large storage capacity can be cheaply obtained, peak-load operation can be economically justified.

In comparing the conditions relating to water-power development in this country with those prevailing on the Continent, several speakers made a particular point of the value of snow storage, which is absent in this country. This comparison is not quite correct, as the difficulty of obtaining adequate storage capacity often prevents the snow storage from being utilized except to a comparatively small extent. Most hydro-electric plants in the Alpine districts, both in Italy and in Switzerland, have been designed as a rule to utilize only the constant minimum natural flow, augmented by certain proportions of the summer flow induced by the melting of the snow for which storage facilities can be made available. It is, however, a well-known fact that, so far as Alpine districts are concerned, difficulties of finding adequate storage facilities have been a definite drawback to a large number of sites which in all other respects would be favourable for power development. In Scotland, on the other hand, the natural facilities for large storage are exceptional, and sufficient capacity to regulate the yearly average flow is available in most of the schemes to which reference is made in the paper.

Dealing with the general question of water power in this country, the interference with fishing rights and the natural amenities of the countryside has been referred to. As regards the former question, it can be definitely proved that, by means of the regulation works now available which allow the creation of artificial spates, and by supplementing the natural flow during any season or in time of excessive drought, matters have been so arranged that fishing has not suffered; indeed, in many cases it has been improved by the formation of new spawning grounds. As regards the spoliation of the countryside and its amenities, this is of course a subject of great controversy, but we maintain that the construction so far completed has caused very little damage to the natural beauties of the locality.

The value of the development of water power in this country from the point of view of the manufacturing industries has been emphasized in the discussion, and we fully endorse the views expressed. The development of manufacture in this country during the last 15 years has been such that the installations built in the last 10 years and referred to in the paper have with minor exceptions employed British equipment throughout, which reflects great credit on the manufacturing concerns.

Dealing with the specific points raised in connection with the design and construction of the Grampian scheme, we regret that within the space at our disposal it is impossible to go adequately into details, but the following is a brief reply to the more important questions referred to in the discussions.

The question whether a vertical or a horizontal setting should be adopted is governed entirely by the local conditions of site and cost of construction, and not by any preference from the mechanical point of view such as has been suggested. The development of the step bearing in connection with vertical machines has been so far advanced that no mechanical trouble need be experienced with the vertical setting, which was adopted for the Rannoch power house after full consideration of the cost of the necessary foundation and buildings for both types. On the contrary, in the Tummel station it was found that the horizontal setting would in practice prove more economical. No difficulty has been experienced with the lubrication of the horizontal bearings.

Turning to the subject of the material for runners, the material to be adopted in each instance is dependent on the question of the effect of cavitation. Owing to the high suction head which had to be adopted at Rannoch, special bronze metal runners were installed as being the best then available, and practically no effect from erosion has so far been experienced. In the Tummel installation, although the conditions governing cavitation are less onerous, it was possible to obtain stainless-steel runners of the larger size necessary, and these were adopted as being the best material for the purpose.

The efficiency tests of the turbines were made by using specially calibrated Pitot tubes, and it is gratifying to record that in each instance the makers' guarantees were actually exceeded during the official tests.

Particular attention was paid at both Rannoch and Tummel power stations to install permanent recording instruments, so that the efficiency of the stations could be recorded and investigated at any particular time.

We agree that the protection of the steelwork, particularly the pipe-lines, is a point of great importance. Experience has proved that in order to get an adequately satisfactory protection for the inside of the pipe-lines great care must be taken to have the internal surfaces both dry and clean before the special bitumastic solutions which are used are applied. The particular procedure adopted in these installations was to apply in a cold state the first coat of special bitumastic solution, and after this first coating had thoroughly dried to apply a protective coating of hot bitumastic enamel. For all external surfaces of the pipe-line, bitumastic enamel was applied hot.

We have not experienced "frazil" or "jelly" ice in this country, as the temperatures in winter are scarcely low or prolonged enough for it to form.

A long spillway is provided at the intake end of the Tummel aqueduct, and in addition a load tank is pro-

vided which automatically comes into action and throws on an artificial load equal to that of a running machine in the event of a main switch tripping. These duplicate measures ensure that there will be no damage from overflow of the aqueduct.

The siphons were adopted to deal with heavy floods, the spillway width possible in the breadth of the river being insufficient for the purpose. The siphons are automatically self-priming, and the discharge capacity varies with the suction head.

Scour pipes and gates were provided at the forebay for the purpose of removing silt.

The screens provided at the intakes for preventing the ingress of debris are of the mesh type, are simple in construction, and will cost little so far as maintenance is concerned. Those in the tailrace at Tummel are of the flat bar form. Special cleaning attention is only necessary on the Tummel aqueduct in the autumn.

When full load is thrown off an alternator at Rannoch, the relief valve comes into operation, a pressure-rise takes place in the pipe-line (which is designed accordingly), and finally the surge shaft comes into use. At Tummel, on the other hand, with its lower head and shorter pipe-line, there is no relief valve, the pipe-line is designed to deal with the full pressure-rise, and the aqueduct acts as the surge shaft. The surge shaft at Rannoch is of stepped design, being wider from about half-way up.

One of the features of the tunnel design was that holes were left in the lining to allow water to penetrate through to the rock and so balance the pressure. The need for testing therefore did not arise. A recent inspection of the tunnel showed the structure to be in perfect condition. Tests have shown that the pipe-line and tunnel losses are within the calculated figures.

If the governor belts broke, the turbine would tend to run up to runaway speed, or would pick up its maximum load, if not otherwise controlled. On the Tummel machine, load-limit control devices are fitted, and if both governor belts break then a switch is operated which fixes the guide vanes in the position where they have been just before the break, so that on a constant load no effect is produced in the load delivered to the system.

With regard to the welding of the Tummel pipes, the whole process was very carefully organized, in regard to both the training of workers and the testing of samples of their work, these checks being constantly maintained throughout the whole job.

The question of transmission is a matter both of economics and of the availability of super-tension and high-tension equipment. Subject to these conditions, there is no reason why large blocks of high load-factor power should not be economically transmitted 200 to 300 miles or more by alternating current, and probably farther by the adoption of a high-tension d.c. system. These distances are as great as any to be met with in this country.

Our experience is that, on the whole, if soundly constructed and properly maintained, high-voltage lines are reliable—even over inaccessible country. It is very seldom that both circuits of a duplicate line give trouble simultaneously. Snow or sleet blizzards are perhaps the worst factor, but in this country they are of short duration. Special care was taken in the design of the Grampian lines to ensure sound mechanical construction, and the experience of 5 years has justified the measures taken.

The Hewlett insulator was chosen largely on account of the nature of the country traversed and the lack of accessibility to the routes during winter months. Experience to date has justified the choice.

The plants run satisfactorily in parallel with the grid, and there is no operating difficulty during normal working. The exciters consist of main and service machines, and these, combined with voltage regulators, boosters, and transformer-tapping arrangements, deal satisfactorily with voltage regulation. So far it has not been necessary to run the Tummel machines as synchronous condensers. This arrangement was provided purely as a precautionary measure, and may never be required.

The rotors were subjected to a 10 per cent over maximum runaway speed test at works, and the erected machines were tested to runaway speed. The brakes are designed to bring the machines to rest in 5 minutes from their application. The machines would run for several hours without braking.

When full load is thrown off suddenly, there is a rise in frequency corresponding to the speed-rise, but the voltage-rise is automatically suppressed.

At the Tummel power station all 11-kV circuits are fully switched and protected. The reactors are, however, treated as an extension to the main busbars and are designed to be equally reliable. The arrangement is not temporary, but it can be amplified and extended if found necessary.

The communication between Tummel and Rannoch is allied to the 33-kV line, and the supervisory control will be developed accordingly; that between Rannoch and Abernethy is allied to the 132-kV line. Both are equally satisfactory.

A commentator points out that, from an engineering point of view, separate regulating transformers are preferable to on-load tap-changing transformers. We entirely support his remarks, and would assure him that the 132-kV system was engineered on this basis throughout.

The Abernethy main transformers are not complicated, and on-load tap-changing is not fitted, since all automatic regulation is done at the power-station ends.

The Abernethy transformers are referred to on page 149; two tappings ($\pm$ 8 per cent) are provided so that the basis for the best operation can be preselected.

The windings of all transformers on the Grampian side of the system are fully insulated throughout, so that the system can be worked either un-earthed or with a limiting resistance in the neutral. In any event, we consider that this is sound engineering practice, but in the Grampian area it is also essential since close parallelism with the G.P.O. lines is unavoidable and, moreover, dead earthing was not considered to be desirable since the severity of the earth faults which would result tends to produce disturbances of far greater magnitude than is the case with the present arrangements. Had dead-earthing been adopted it would have been impracticable to have carried out the extensions to the 132-kV system which

are now under review, because in the Grampian area the topography of the country provides a limited number of transmission-line routes and these have already been selected for roads, railways, and telegraph lines, and the addition of transmission lines in these channels obviously presents engineering difficulties which the flexible earthing arrangements that can be adopted on the Grampian Electricity Supply Co.'s system are able to meet.

The capacitance bushings at Abernethy provide the equivalent of a 132-kV neutral potential transformer and are used in conjunction with selector earth-leakage relays for protection of the 132-kV lines.

The automatic load controller enables the Tummel station to deliver a constant load when in parallel with other stations; the frequency controller is for use when the station is supplying a fluctuating load.

The negative phase-sequence protection does not normally act on faults external to the system, as it is essentially stand-by protection and the time grading is set accordingly.

With regard to the 4-circuit lines, voltage is induced in the other circuits under fault conditions. This was appreciated in working out the design, arrangements were made accordingly, and no trouble has been experienced.

Lightning storms have been frequent over the Grampian area, but, so far as observation can tell, the graded gaps show no signs of having functioned. The settings of the gaps are the maximum that can be adopted without permitting voltages to pass that would cause breakdown of transformers.

The air-break isolators both make and break transformer magnetizing-currents satisfactorily. When line-charging current has to be broken, the switches are interlocked so that they cannot be opened unless the current is limited to a safe value.

Good earthing connections are difficult to obtain; earthing tubes spaced 6 ft. or more apart have been liberally used, together with buried copper strip. All earthing points are continuously bonded together throughout the whole area.

The Grampian Electricity Supply Co. is at present actively developing the supply to the north and north-east portions of Scotland, and, so far as we know, there is no intention to extend the grid lines to this part of the area.

DISCUSSION ON

"THE DEVELOPMENT OF A SENSITIVE PRECISION WATTMETER FOR THE MEASUREMENT OF VERY SMALL POWERS."*

Mr. A. Campbell (*communicated*): This paper shows how careful scientific method of design is almost sure to lead to satisfactory results.

More than 20 years ago we set up at the National Physical Laboratory a standard reflecting wattmeter for iron testing, and it is still in regular use for that purpose. Its period (damped) is about 25 secs. When reduced to the same conditions as the author's, it is about one-fifth as sensitive as his instrument. The simple direct-deflection method is used at the National Physical Laboratory and has not been found disadvantageous. I may remark that null methods can be used with an ordinary wattmeter without the addition of a direct-current system like that of Dr. Searby.†

With regard to iron testing, it is quite true that the use of large samples (e.g. 10 kg) is wasteful, and even the 2 kg used in Lloyd Fisher and Churcher's methods seems large; but with smaller amounts the sampling cannot be quite satisfactory, and the effects of the cutting (on the magnetic properties) may cause considerable error. For dispute tests, a recent specification prescribes a minimum width of 7 cm for sheet samples, and this almost necessarily means a heavy sample.

I have no doubt, however, that there are other applications in which the author's highly sensitive instrument will prove most useful.

Dr. N. Halifax Searby (*in reply*): I am gratified by Mr. Campbell's remarks with regard to the sensitivity of my instrument, but I feel that if he had further acquaintance with the direct-current control scheme instead of a torsion-head type (both employing a null method), he would find very noticeable the increased ease and speed of manipulation obtained by being able to adjust the control without touching or disturbing the instrument. The range of the instrument is also thereby immensely increased.

With regard to iron testing with small samples, e.g. say 200 grammes, I cannot see that sampling would be less satisfactory. In any case, with such small weights a greater number of samples could be tested and the final results would clearly be more representative. The effects of the cutting on the magnetic properties could, I understand, be obviated by subjecting the cut samples to the same annealing or other heat-treatment process as that to which the sheets had already been subjected.

* Paper by Dr. N. Halifax Searby (see page 205).

† See A. Campbell: *Electrical Review*, 1905, vol. 56, p. 128.

DISCUSSION ON

"MODERN PRACTICE IN GERMANY AND THE EUROPEAN CONTINENT WITH REGARD TO SUPERVISORY CONTROL SYSTEMS AS APPLIED TO LARGE INTERCONNECTED SUPPLY AREAS."*

Mr. E. Lapeyre (France) (*communicated*): In the Appendix to the paper the author gives some particulars of the Union d'Électricité, Paris, which are not in accordance with facts, and which I should therefore like to correct. He remarks on page 721 (vol. 75) in connection with this company that:

"At present it owns only comparatively small generating stations. Two of these possess a combined installed capacity of 116 000 kW (Gennevilliers 36 000 kW, and Vitry-Nord 80 000 kW), and are used for the general supply. The Nanterre (20 000 kW) and Issy-les-Moulineux (20 000 kW) stations supply current for traction. There are, however, three large stations under construction, or proposed, of a combined installed capacity of 720 000 kW. Apart from these stations, energy from water power is obtained from the Massif power station, of which the installed capacity is 75 000 kW."

Actually the facts are that the Union d'Électricité operates two central stations, Gennevilliers (340 000 kW), and Arrighi-Vitry-Sud (220 000 kW), with a total installed capacity of 560 000 kW. The Vitry-Nord, Nanterre, and Issy-les-Moulineux generating stations are no longer in service. The 66 000-volt system of the Union d'Électricité, fed by its central stations, is interconnected by means of two 90-kV and one 220-kV transmission lines with the water-power station of the Massif Central, the installed capacity of which exceeds 450 000 kW. Moreover, the stations of the Société d'Électricité de Paris, the Société d'Électricité de la Seine, and the Compagnie Parisienne de Distribution d'Électricité, are also interconnected with the system of the Union d'Électricité. The total installed capacity of the interconnected stations feeding the 60-kV network of the Paris district, either directly or through the transmission lines of the Massif power station, is of the order of 1 500 000 kW. The load-dispatching plant of the entire system is therefore an important one. It embodies all the most modern improvements, and permits of continuous control over the whole network, which stretches from north to south over a distance of nearly 600 km.

* Paper by Dr. M. Schleicher (see vol. 75, p. 710).

INSTITUTION NOTES.

Electrical Engineers' Ball.

The Committee of Management of the Benevolent Fund are glad to report that the Fund has benefited to the extent of £244 2s. 6d. as a result of the Ball held on the 8th February last, this amount being the surplus available after defraying all expenses. The attendance was over 1 000.

Index to Journal.

Any member who proposes to bind the current volume of the *Journal* and would like to have an extra copy of the Index for filing apart from the bound copy of the *Journal* can obtain an additional copy on application to the Secretary.

Overseas Members and the Institution.

During the period 1st January to 31st May, 1935, the following members from overseas called at the Institution and signed the "Attendance Register of Overseas Members":—

Babits, Dr. V. A. (*Budapest*).
Ball, W. C. D. (*Singapore*).
Bristow, G. W., B.Sc. (Eng.) (*Singapore*).
Critchley, V. F. (*Lahore*).
Foster, A. D., M.Sc. (*Abadan, Persia*).
Guilford, A. L., B.Sc.Tech. (*Bombay*).
Harper, H. R. (*Melbourne*).
Harris, B. J. (*Gisborne, N.Z.*).
Higgs, E. P., B.Sc.(Eng.) (*Shanghai*).
Howard, H. G. (*Madras*).
MacGregor, W. D., C.I.E. (*Burma*).
Matthewman, Prof. T. H. (*Lahore*).
Moscardo, F. (*Valencia, Spain*).
Nutt, A. (*Klipheuvel, S. Africa*).
Oliphant, T. (*Shanghai*).
Phillips, C. G. R. (*Kuala Lumpur, F.M.S.*).
Siddeley, H. C. (*Buenos Aires*).
Still, A. (*Seattle, U.S.A.*).
Suggate, Lieut.-Col. C. F. D., M.C., R.A.O.C. (*Allahabad*).
Thrupp, F. E. M. (*Milan*).
Turner, L. G. H. (*Bombay*).
Watkins, A. W. M. (*Christchurch, N.Z.*).
Webb, C. R. (*Shanghai*).
Winson, V. H., B.Sc.(Eng.) (*Kuala Lumpur, F.M.S.*).

Mr. Hodge's Address to Western Centre.

The Secretary has received the following communication from Mr. R. Hodge, Chairman of the Western Centre:—

"In connection with my Address as Chairman of the Western Centre (see *Journal*, No. 457, January, 1935), I find on further investigation that an error occurred therein on page 38, col. 2, where I stated that 'a quarter of a century ago 18½ lb. of coal were required to generate one unit of electricity.' The average figure should have been 4 to 5 lb. of coal per unit generated."

Council's Nominations for Election to the Council.

The following have been nominated by the Council for the vacancies which will occur in the offices of President, Vice-President, Honorary Treasurer, and Ordinary Members of Council, on the 30th September, 1935:—

President. (*One Vacancy.*)
J. M. Kennedy.

Vice-President. (*One Vacancy.*)
A. P. M. Fleming, C.B.E., M.Sc.

Honorary Treasurer. (*One Vacancy.*)
F. W. Crawter.

Ordinary Members of Council.
MEMBERS. (*Three Vacancies.*)
E. S. Byng. P. Good.
Prof. C. L. Fortescue, O.B.E., M.A.

ASSOCIATE MEMBERS. (*One Vacancy.*)
F. E. J. Ockenden.

Premiums.

The Council have made the following awards of Premiums for papers read during the session 1934–35 or accepted for publication only:—

The Institution Premium (*value* £25).
Sir NOEL ASHBRIDGE, B.Sc. (Eng.), H. BISHOP, B.Sc. (Eng.), and B. N. MACLARTY — "The Droitwich Broadcasting Station."

The Ayrton Premium (*value* £10).
R. GRIERSON and D. BETTS — "The Electrical Warming of, and the Supply of Hot Water and Conditioned Air to, Large Buildings."

The Fahie Premium (*value* £10).
W. WEST, B.A., and D. McMILLAN, B.Sc. — "Characteristics of Telephone Receivers."

The John Hopkinson Premium (*value* £10).
W. D. HORSLEY — "The Stability Characteristics of Alternators and of Large Interconnected Systems."

The Kelvin Premium (*value* £10).
C. E. WEBB, B.Sc., and L. H. FORD, B.Sc. — "The Time-Decrease of Permeability at Low Magnetizing Forces." *And* "Alternating-Current Permeability and the Bridge Method of Magnetic Testing."

The Paris Exhibition (1881) *Premium* (*value* £10).
A. MONKHOUSE — "Electrical Developments in the U.S.S.R."

A Premium (*value* £10).

T. E. ALLIBONE, Ph.D., M.Sc., W. G. HAWLEY, and F. R. PERRY, M.Sc.Tech. — "Cathode-Ray Oscillographic Studies of Surge Phenomena."

A Premium (*value* £10).

C. WALLACE SAUNDERS, H. W. WILSON, and R. G. JAKEMAN, D.Sc. — "Generation, Distribution, and Use, of Electricity on Board Ship."

A Premium (*value* £5).

E. S. BYNG — "The Engineer Administrator."

A Premium (*value* £5).

C. M. LONGFIELD, M. Eng. — "The Practical Solution of Stray-Current Electrolysis."

A Premium (*value* £5).

R. POOLE — "The Application of Propeller Fans to the Cooling of Electrical Machines."

A Premium (*value* £5).

J. C. PRESCOTT, D.Eng., and J. E. RICHARDSON, Ph.D. — "The Inherent Instability of Synchronous Machinery."

An Overseas Premium (*value* £10).

F. T. M. KISSEL, B.Sc. — "The Organization of Electricity Supply in New Zealand."

WIRELESS SECTION PREMIUMS.

The Duddell Premium (*value* £20).

C. F. BOOTH and E. J. C. DIXON, B.Sc. — "Crystal Oscillators for Radio Transmitters."

A Premium (*value* £10).

R. H. BARFIELD, M.Sc. (Eng.) — "Some Principles underlying the Design of Spaced-Aerial Direction-Finders."

A Premium (*value* £10).

C. R. BURCH, B.A., and C. SYKES, Ph.D., M.Sc. — "Continuously Evacuated Valves and their Associated Equipment."

METER AND INSTRUMENT SECTION PREMIUMS.

The Silvanus Thompson Premium (*value* £10).

N. H. SEARBY, Ph.D. — "The Development of a Sensitive Precision Wattmeter for the Measurement of Very Small Powers."

A Premium (*value* £5).

Prof. J. T. MACGREGOR-MORRIS and J. A. HENLEY, B.Sc.(Eng.) — "The Theoretical and Practical Sensitivities of Gas-Focused Cathode-Ray Oscillographs, and Effects of the Gas on their Performance."

TRANSMISSION SECTION PREMIUMS.

The Sebastian de Ferranti Premium (*value* £20).

D. M. ROBINSON, Ph.D. — "The Breakdown Mechanism of Impregnated Paper Cables."

A Premium (*value* £10).

W. J. JOHN and F. M. SAYERS — "Transmission-Line Insulators under Deposit Conditions."

The awards for papers read before the Students' Sections will be published in a later issue of the *Journal*.

Elections and Transfers.

At the Ordinary Meeting of the Institution held on the 11th April, 1935, the following elections and transfers were effected:—

ELECTIONS.

Associate Members.

Anderson, James Alexander.
Bannerman, George Henry M.
Bowen, Commander John Herbert.
Capponi, Count Ferrante.
Dodds, Tom.
Draffin, George Francey, B.Sc., B.E.
Garnett, Cuthbert Victor H., M.A.
Guthrie, William, B.Sc.
Head, Arthur Harry T.
Howell, James Walter.
Kelsey, Thomas Hubert, M.A.
Kopp, Eugene.
Levi, Gustav, D.Eng.
Lowde, Ernest Alfred.
Mann, Frederick Watson, B.Sc.
Manning, Francis George, B.Sc.(Eng.).
Peet, William Vallis, B.A., B.A.I.
Scaife, Frederick Noel, B.Sc.
Stoerk, Carl, Dipl. Ing.

Companion.

Boothman, James.

Associates.

Dowsett, James.
Ferrer, William.
Kant, Thomas Young.
Laverick, Percy William.

Graduates.

Agrawala, Hira Lal, B.Sc. (Eng.).
Beardmore, Ronald Jabez.
Binns, Joshua William.
Bousfield, William Arthur.
Chellam, Sankaranaiayana Venkatanarayana.
Chunilal, Vaikunth.
Dave, Narmadashankar Manishankar, B.Sc. (Eng.).
Delamare, Alfred Charles.
De Salis, Arthur Regester F., B.A.
de Villiers, Hendrik Johannes, B.Sc.
D'Souza, Alfred.
Firth, Thomas Rhodes.
Fulton, John James K., B.A., B.A.I.
Ghosh, Jibananda.
Hillary, Harry White.
Iliff, Edward Durnford, B.Sc.(Eng.).
Jesuratnam, Samuel, B.A., B.Sc.
Jones, Edward Guthrie, B.A.
McIntyre, Colin.
Mayall, Reginald Edward.
Mead, Wilfred Ernest.
Nair, V. K. Raghavan.
Needham, Henry Joseph.
Prentice, Sydney Arthur, B.E.E.
Rajagopalan, Kumbakonam Ramanuja.
Read, George Stuart J., B.Sc.
Sanderson, Kenneth Corlyon, B.Sc.

Graduates—continued.

Shukla, Ramnarayan Bhawaniprasad.
Sinha, Shiva Nandan P., B.Sc.(Eng.).
Smith, Clive Gordon, M.A.
Snowdon, John Walter, B.Sc.
Todd, John Hayhurst.

Students.

Anderson, Arthur William.
Anwar-Ali, Chaudhary.
Arrol, James Crookston.
Bapat, Waman Vinayak, B.Sc.(Eng.).
Bartle, Clifford John.
Bates, Geoffrey Hermann.
Beveridge, Clifford.
Bharucha, Jamshed Hirjibhoy, B.Sc.
Binstead, Eric.
Boundy, James Reilly.
Brownbridge, Clifford.
Bruell, Robert Erwin.
Coueslant, Frank.
Crisp, Donald Harry.
Crowther, Stanley Thomas.
Din, Zahur-Ud.
Edwards, Laurence William.
Eggleton, Charles William.
Evans, Norman Leopold.
Farrall, Robert.
Fox, Edgar Sydney.
French, William Frederick.
George, John Maxim B.
Ghose, M. K.
Gibson, Horace Lawrence.
Grant, John Campbell.
Gregory, John Pearson.
Guest, George Philip.
Gupta, Shanti Chander.
Hands, Thomas.
Harvey, Alan Peterson.
Hindoss, Henry Gordon.
Hodgkinson, Walter.
Huey, James.
Hughes, Cecil John.
Jackson, Maurice George A.
Joice, William Arnold.
Jones, Ernest Brandon.
Kennedy, William.
Khushalani, Rewachand Nenumal, B.Sc.(Eng.).
MacGregor, James Gillespie.
McIntosh, John.
Martindale, Robinson George.
Moorcroft, George James.
Morgan, Wilfred Francis R.
Newby, Robert William.
Park, Robert William.
Pearce, Charles Henry.
Piggott, John.
Poulton, Reginald Charles K.
Rae, William James S.
Randal, Alan Norman E.
Rewcastle, John Jermy.
Reynolds, Herbert.
Richards, John Thomas L.
Ritchie, Gilbert.
Roberts, David, Junr.
Rouse, Henry Frederick.
Roy, Mugada Ramanohan.
Rumsam, Cecil George.
Ryland, Arnold.
Sach, Norman Daniel.
Scofield, William Ormsby.
Scrutton, Frank Richard.
Sharp, Donald Stanley.
Shashoua, Stafford.
Shave, Charles Edward D.
Spencer, Edward John C.
Symonds, Alan.
Taylor, Gerald Richard.
Taylor, John Johnson.
Tyrrell, John Longstaff.
Wadsworth, David.
Walters, Horace John.
Wardle, Thomas Robinson.
Watkin, John Robert.
Webb, Kenneth Frank.
White, Donald Frederic.
Wilmot, Thomas Arthur W.
Winstanley, Edward.
Yadukulatilakam, S. N., B.Sc.(Eng.).

TRANSFERS.

Associate Member to Member.

Abell, Robert Henry.
Brake, Francis Joseph E.
Cooper, William John.
Picken, William James.
Wilkinson, John Reed, B.Sc.Tech.

Associate to Associate Member.

Mitchell, John Albert.

Graduate to Associate Member.

Beggs, David Norman, B.Sc.Tech.
Bray, George Rupert R., B.Sc.
Broadhurst, Jack.
Brookes, Cyril Spencer.
Cully, Richard Howard.
de Beer, Charles Loxton.
Dewsnup, Roger Ritson, B.Eng.
Dwyer, Colin Henry.
Flower, John Edward.
French, William Leslie M.
Goodyear, Herbert William, B.Sc.(Eng.).
Hawker, Michael Seymour.
Jones, Geoffrey Charles.
Kay, Edward John R., B.Sc.
Kelly, William Swan, B.Sc.
Moore, Ronald Frank.
Neale, Ronald Douglas, B.E.
Priestley, Frank.
Quinton, Harold Frederick, B.Sc.(Eng.).
Whiteley, Claude Stuart.

Student to Associate Member.

Caddell, Henry Alfred P., B.A.
Pepworth, Frederick James.

In addition, the following transfers have been effected by the Council:—

Student to Graduate.

Bailey, Desmond.
Barge, Rupert Maurice.
Bhatt, Induprasad Chhotalal, B.Sc.(Eng.).
Burrell, Maurice Barnard F.
Cameron, Robert Millar Y.
Champion, Bernard Harden.
Chinoy, Habib Nurmahomed.
Clarke, Alan Charles W. V., B.Sc.(Eng.).
Corney, Lawrence Arthur, B.Sc.(Eng.).
Cousland, Sidney Thomas G., B.Sc.
Craven, Arthur Swift.
Dalton, Charles Ernest W.
Davis, William James.
Dawson, Richard Gillon.
Day, William John.
Easterbrook, Leonard Arthur.
Gibson, Alan Barraclough, B.Eng.
Gillespie, Miles Lamport, B.Sc.
Griffin, Robert.
Hackett, Max Sloan.
Hitchcox, Gerald Ivor.
Howie, Thomas, B.Sc.
Ilsley, John Linton, B.Sc.(Eng.).
Irwin, John.
Khanna, Madan Lal.
Kerkham, William Andrew, B.Sc.(Eng.).
Loudon, David McKinlay.
Macan, Robert.
Maurice, Ronald Frank.
Milner, Arnold Keith.
Patch, Wilfred Percy, B.Sc.(Eng.).
Percy, James Douglas.
Preddle, Norman Frederick.
Pulvermacher, Paul Leopold.
Rao, Bantwal Sadashiva, B.Sc.
Schofield, Geoffrey.
Sheppard, Henry John, B.Sc.
Small, William Hubert.
Suttle, Charles Edward P., B.Sc.(Eng.).
Walden, Eric Robert, B.Sc.(Eng.).
Webster, Gilbert Harold, B.Eng.
Whiting, Frank William, B.Sc.(Eng.).

Accessions to the Reference Library.

[NOTE.—The books cannot be purchased at the Institution; the names of the publishers and the prices are given only for the convenience of members; (*) denotes that the book is also in the Lending Library.

STUDHOLME, R. H., *M.A.* Electricity law and practice. A handbook of the application and effect of the Electricity (Supply) Acts, 1882 to 1935. With a foreword by the Rt. Hon. Sir T. Inskip. 8vo. xxx + 472 + 29 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1935.) 30*s*. (*)

THORPE, *Sir* E., *C.B.*, *LL.D.*, *F.R.S.* Dictionary of applied chemistry. Supplement, by J. F. Thorpe and M. A. Whiteley. vol. 1. 8vo. xxi + 680 pp. (London: Longmans, Green and Co., Ltd., 1934.) 60*s*.

TUTIN, J., *D.Sc.* The atom. With an introduction by F. Soddy. 8vo. 109 pp. (London: Longmans, Green and Co., 1934.) 6*s*. (*)

VERNON, H. M., *M.A.*, *M.D.* The principles of heating and ventilation. 8vo. viii + 232 pp. (London: Edward Arnold and Co., 1934.) 14*s*. (*)

WADDICOR, H., *B.Sc.* The principles of electric power transmission by alternating currents. 3rd ed. 8vo. xxi + 449 pp. (London: Chapman and Hall, Ltd., 1935.) 21*s*. (*)

WALKER, R. C., and LANCE, T. M. C. Photoelectric cell applications. A practical book describing the uses of photoelectric cells in television, talking pictures, electrical alarms, counting devices, etc. 2nd ed. 8vo. x + 245 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1935.) 8*s*. 6*d*. (*)

WALTER, M., *Dr.-Ing.* Der Selektivschutz nach dem Widerstandsprinzip. 8vo 172 pp. (München: Verlag von R. Oldenbourg, 1933.) *RM.* 8.50.

WHITTAKER'S arithmetic of electrical engineering. 4th ed., revised by A. T. Starr. sm. 8vo. ix + 193 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1934.) 3*s*. 6*d*. (*)

WILSON, H. A., *M.A.*, *M.Sc.*, *F.R.S.* The mysteries of the atom. 8vo. vi + 146 pp. (London: Chapman and Hall, Ltd., 1934.) 10*s*. 6*d*. (*)

WITTS, A. T. The superheterodyne receiver: its development, theory and modern practice. sm. 8vo. vii + 128 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1935.) 3*s*. 6*d*. (*)

WOOD, A., *M.A.*, *D.Sc.* Joule and the study of energy. sm. 8vo. viii + 88 pp. (London: G. Bell and Sons, Ltd., 1925.) 1*s*. 6*d*.

WORLD list of scientific periodicals published in the years 1900–1933. 2nd ed. 4to. xiv + 780 pp. (London: Oxford University Press, 1934.) 63*s*.

WORLD POWER CONFERENCE. Sectional meeting, Scandinavia. 1933. Transactions. 7 vol. la. 8vo. (Stockholm: Svenska Nationalkommittén för Varldskraftkonferenser; London: Percy Lund, Humphries and Co., Ltd., 1934.) 175*s*.

vol. 1, General.—Index. 50*s*.
vol. 2, Electrical energy. 50*s*.
vol. 3, Gas, solid and liquid fuels. 25*s*.
vol. 4, Power and heat combinations.—Steam heat consuming industries. 45*s*.
vol. 5, Iron and steel industry.—Electrical heating.—Transmission and adaptation of motive power for industrial machinery. 50*s*.
vol. 6, Railways, urban and suburban traffic. 55*s*.
vol. 7, Marine transport. 20*s*.

WYBROW, S. G. Electrical and wireless equipment of aircraft, including the repair, overhaul and testing of magnetos. 8vo. viii + 131 pp. London: Sir Isaac Pitman and Sons, Ltd., 1934.) 6*s*. (*)

ZABRANSKY, H., *Dr.-Ing.* Die Drehzahlregelung von Asynchronmotoren durch Wechselstrom - Kommutatorhintermaschinen. 8vo. vi + 208 pp. (Berlin: Carl Heymanns Verlag, 1934.) *RM.* 16.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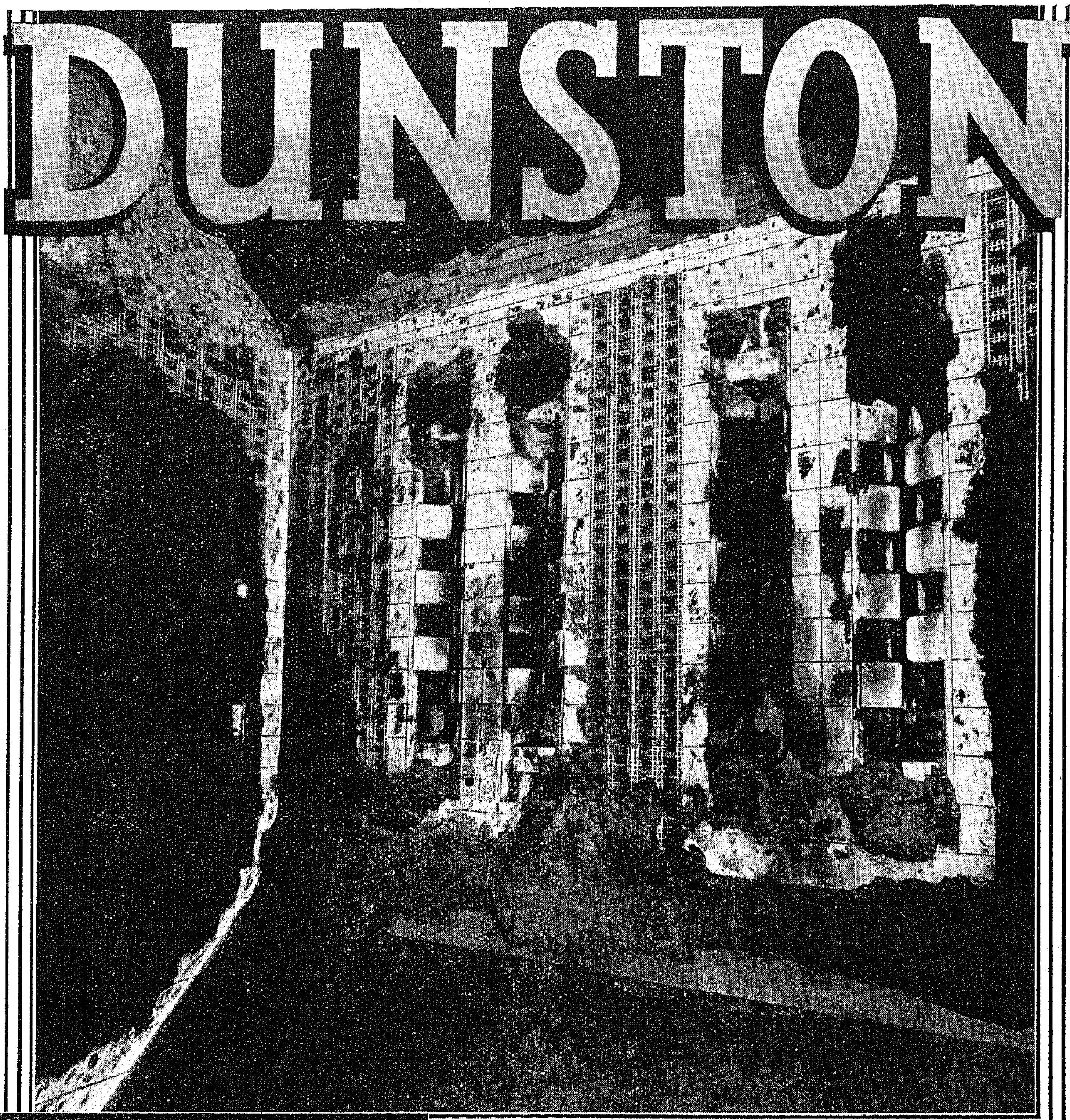

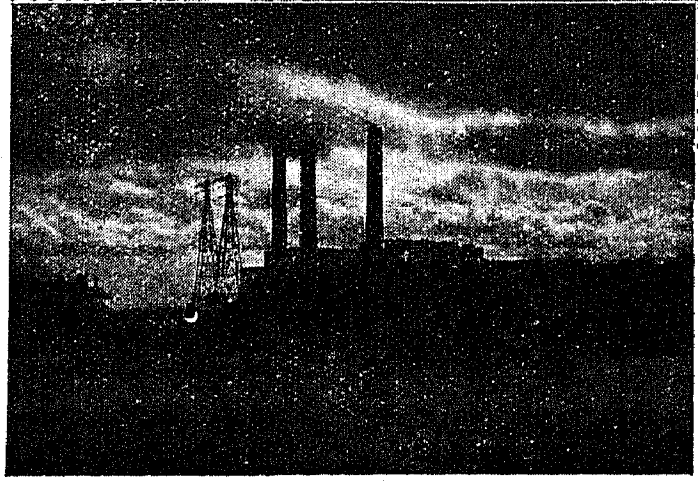

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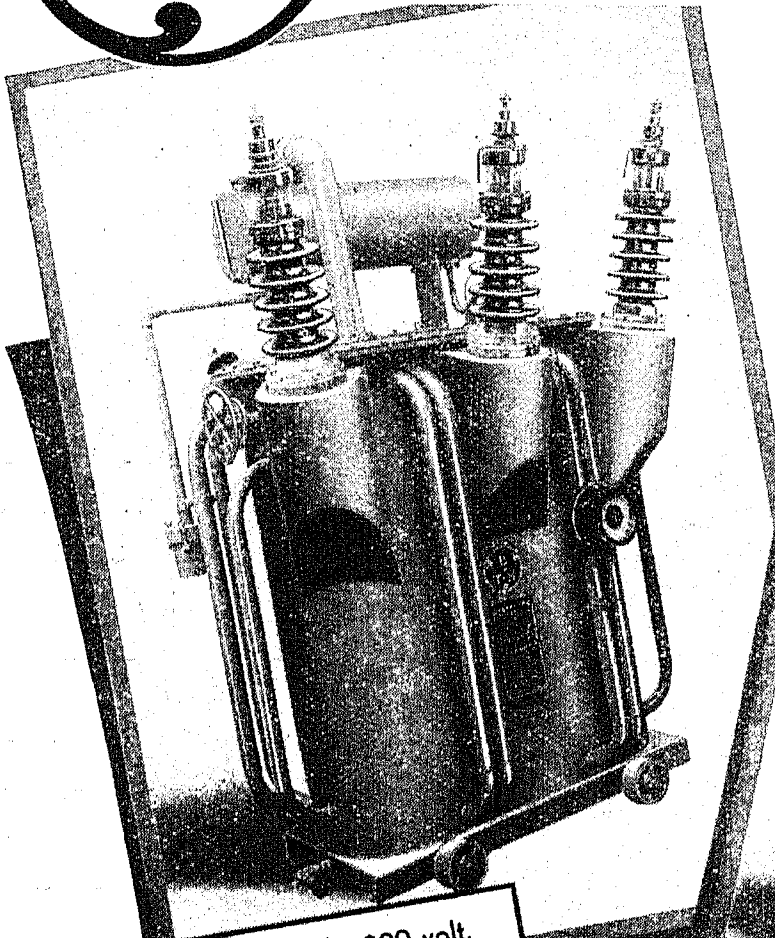

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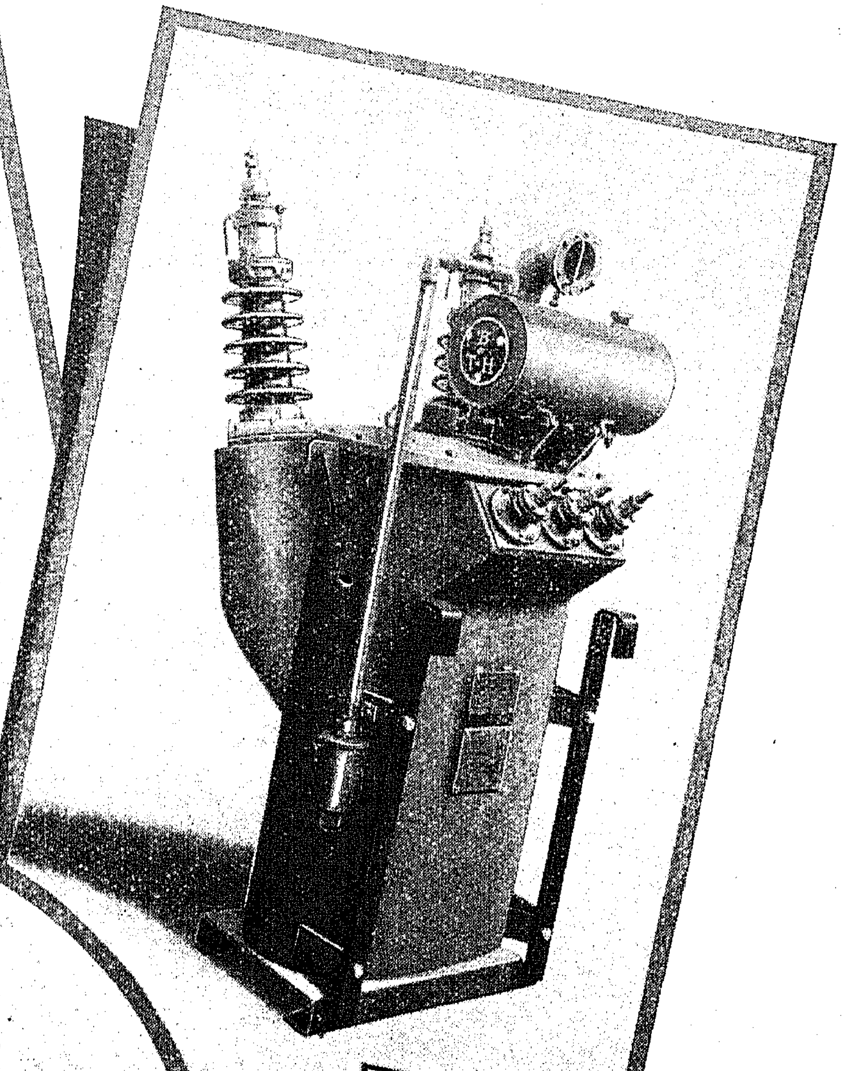

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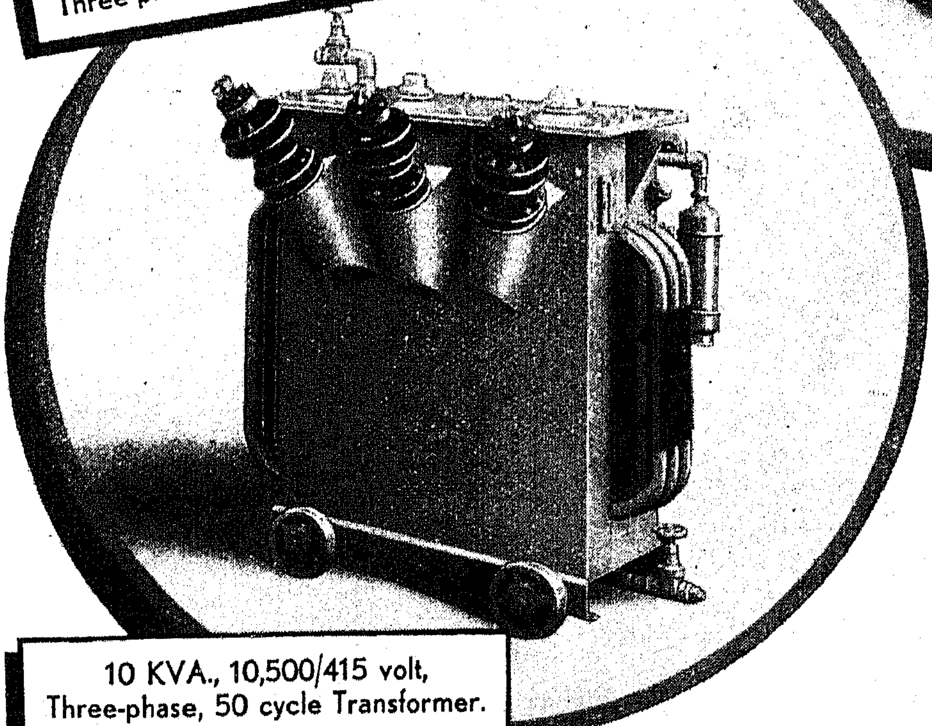

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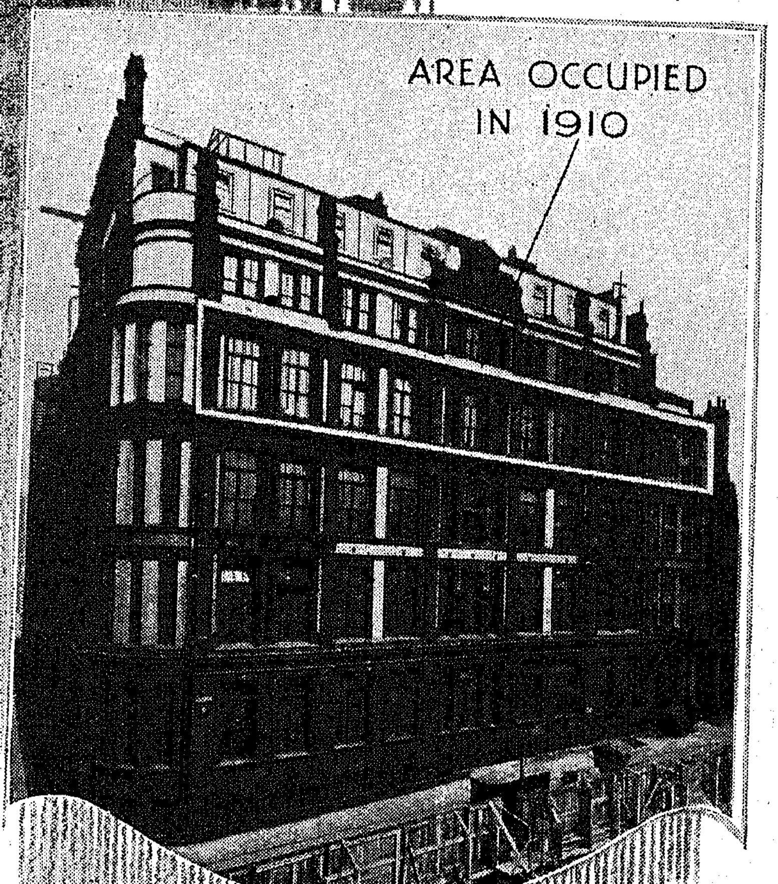

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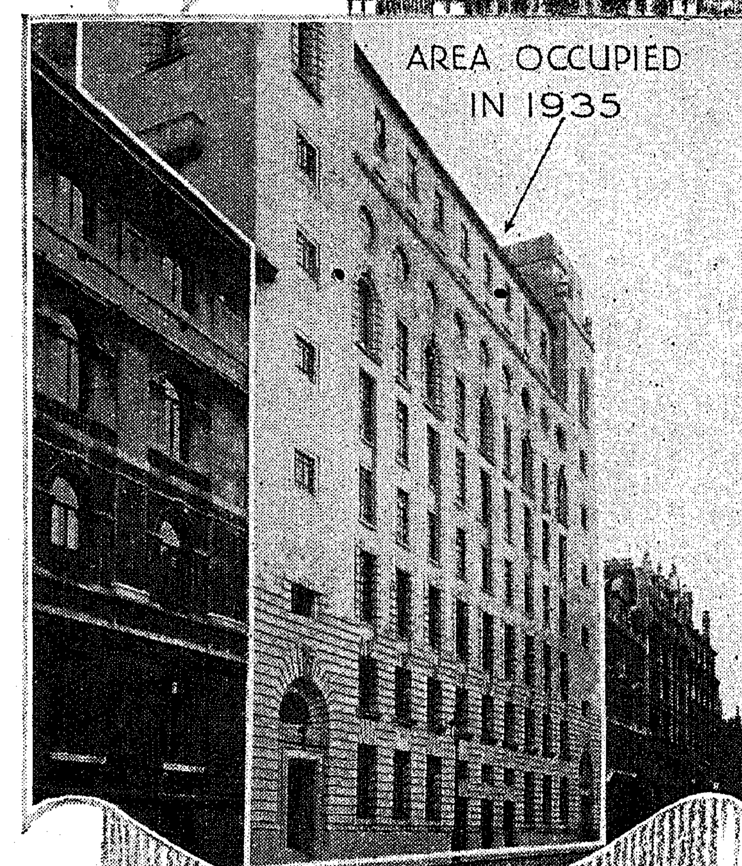

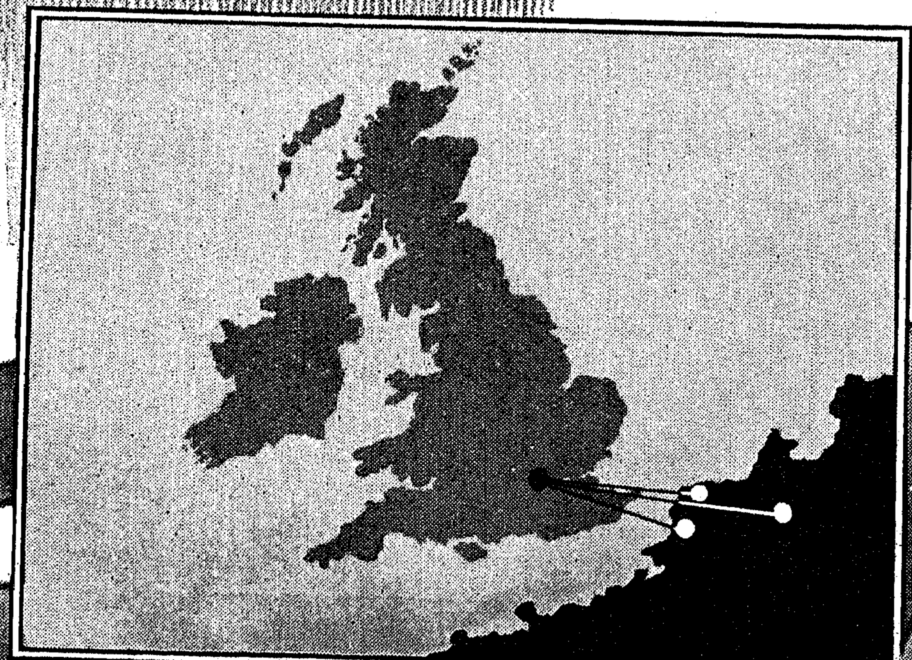

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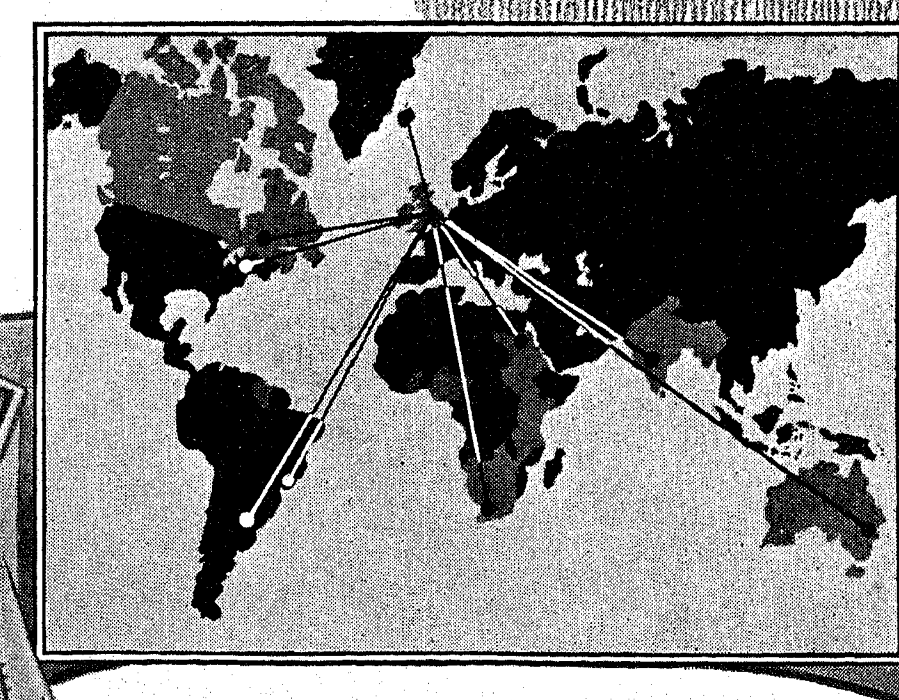

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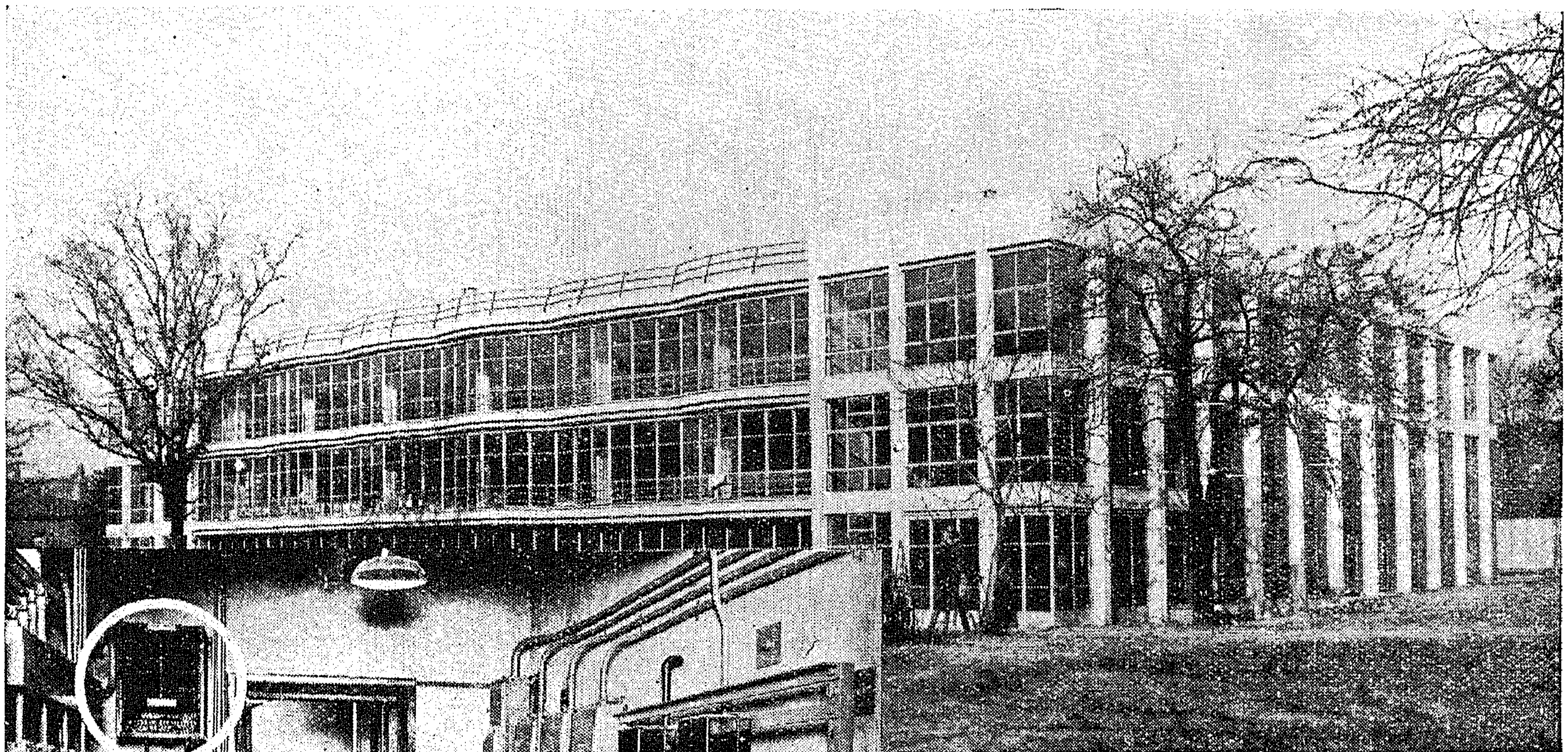
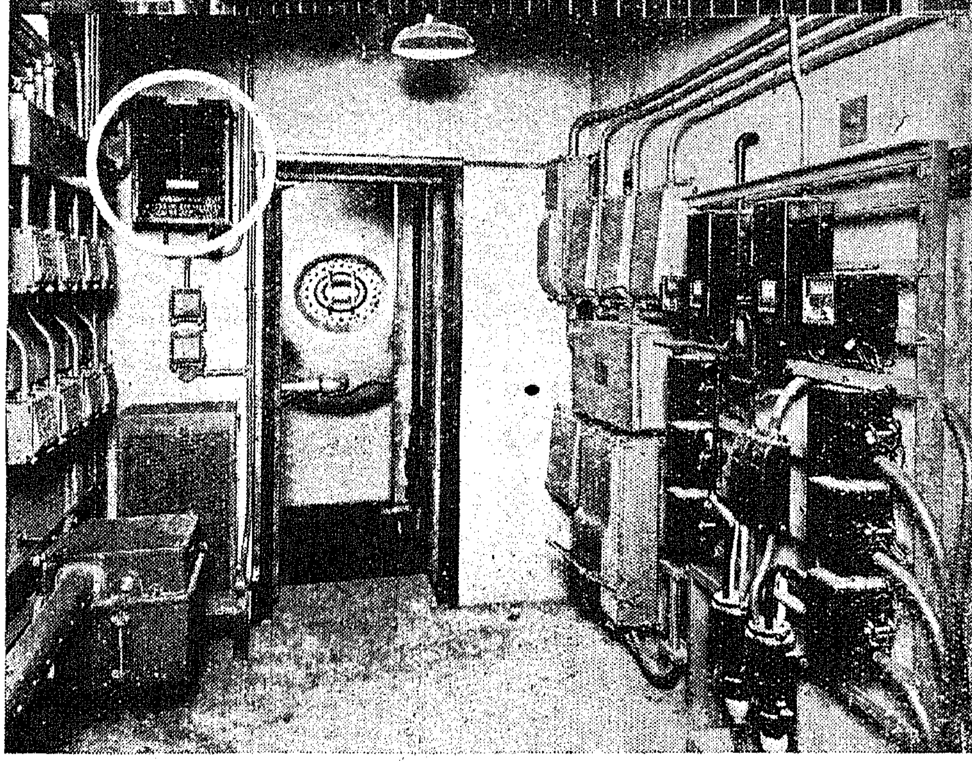
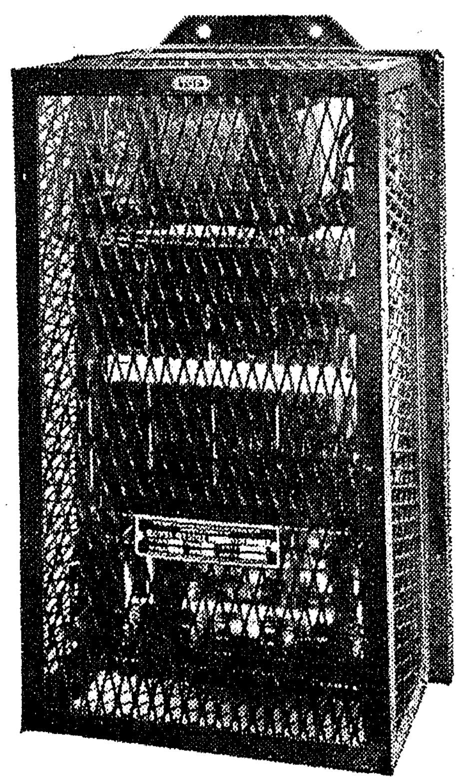




Photograph by courtesy of "The Electrical Review."



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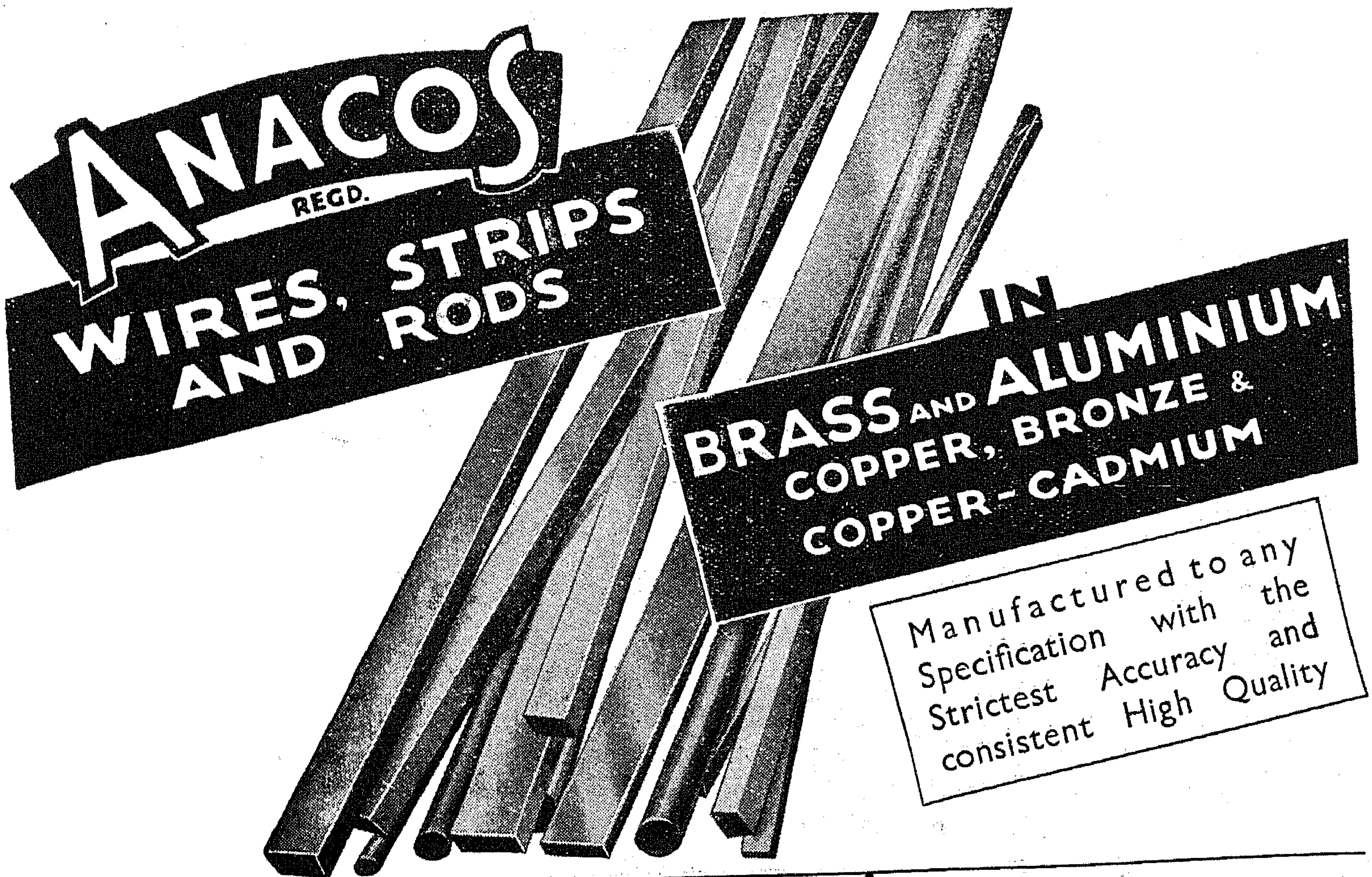

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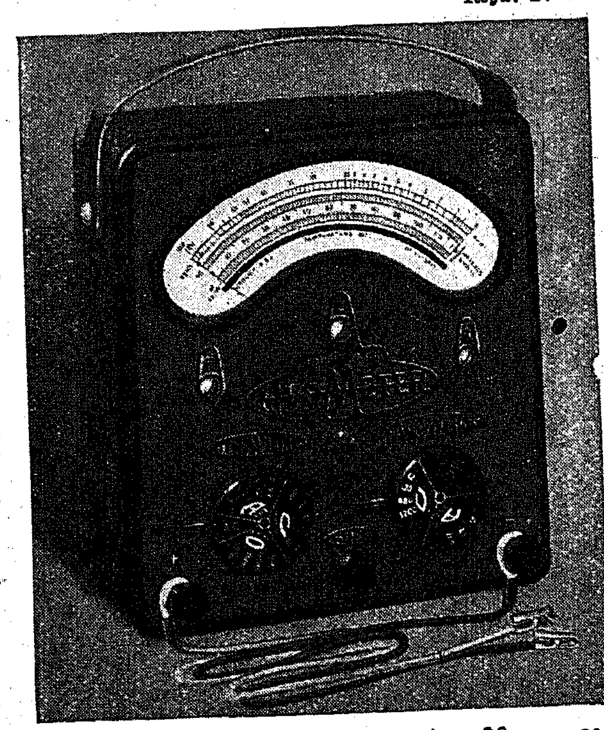

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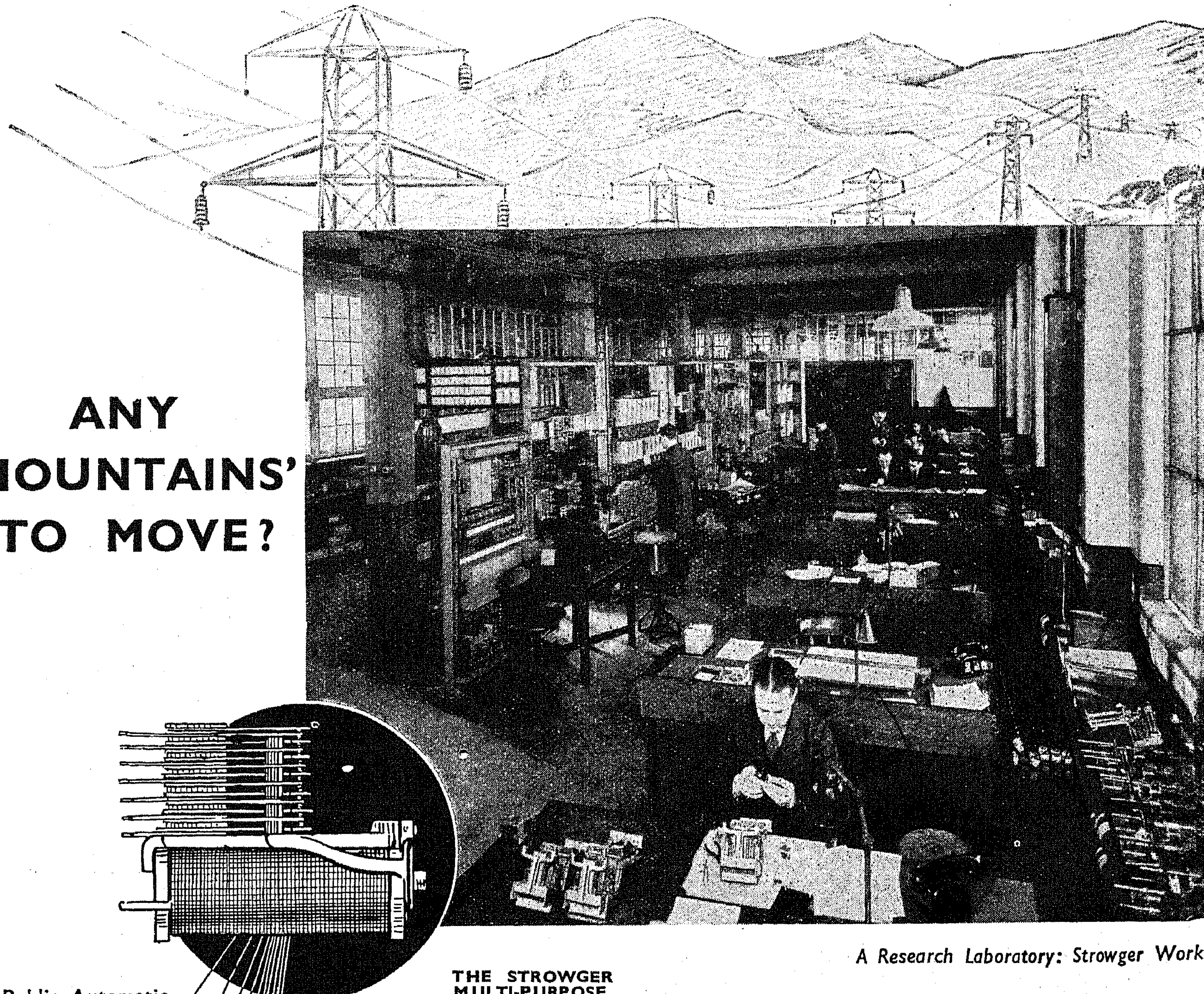

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